Chapter 15

NASA "Safe Wing"
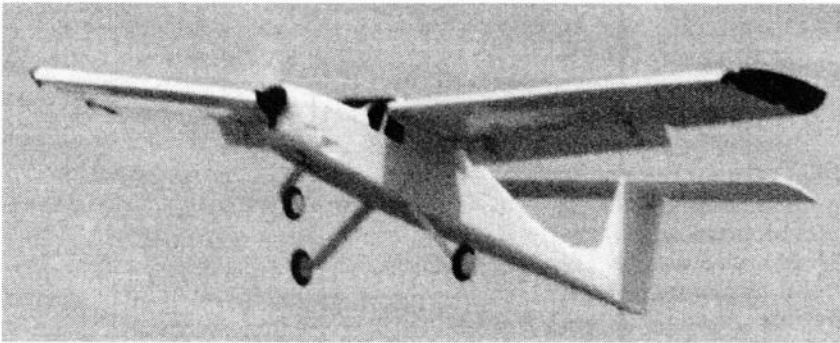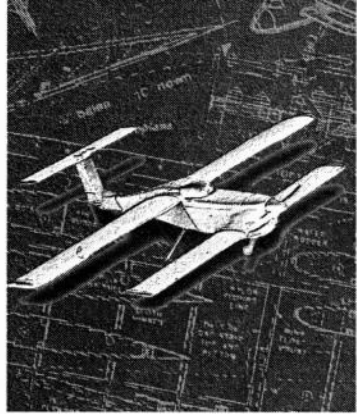

The Snowy Owl in slow-speed flight with flaps extended. The increasing leading-edge droop ahead of the ailerons is clearly visible.

Here's a grim statistic: roughly 30 percent of all fatal accidents involving light, full-scale airplanes are caused by stalling and spinning at low altitudes, and ground impact occurs before the spin fully develops. Several members of my club have discovered that R/C model aircraft are also prone to this insidious failure. What's happening?

As a private pilot, I've been interested in wing modifications that will improve the stall/spin characteristics of both full-scale and R/C model airplanes. Most modelers know that a model's wing lift is proportional to the square of its air-speed. At the same AoA, doubling the speed increases lift fourfold. Also, lift varies directly with the AoA, from the airfoil's zero lift angle to its stalling angle. In high-speed flight, the wing operates at a low AoA; at low speed, that angle must be increased to maintain level flight. The stalling angle of the wing's airfoil determines the lowest speed limit.

Centrifugal force plays a significant part in stalls and spins because it increases the weight that the wing must support. It's encoun-tered when banking steeply, sharply pulling up into climbs, and when you panic and use full-up-elevator when pulling out of dives at low altitude.

For example, a full-scale Cessna 172 at gross weight stalls at 57mph. In a 60-degree banked turn, its stall speed increases by 42 percent to 81mph, and this is due entirely to the extra load imposed by centrifugal force. As a normal wing approaches the stalling angle, ai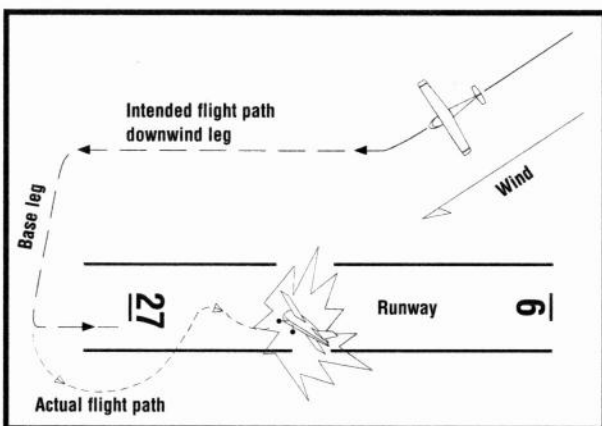leron-control effectiveness deteriorates markedly. Lowering an aileron to introduce a roll input at this angle increases the wing's AoA at that aileron, and may cause it to stall—just the opposite of the action commanded by the pilot.

A TRAGIC SCENE

Suppose an inexperienced pilot is flying a high-wing aircraft. He's in a left-hand pattern for landing at a busy airport, and a light crosswind is blowing from left to right. After turning onto the base leg of his approach, he slows the airplane by throttling back and increasing its AoA by applying up-elevator. While scanning the area for other traffic, he lowers the flaps, trims the aircraft and announces his intention to land.

At an altitude of 300 feet, he turns left again onto final approach, and our inexperienced aviator finds that the crosswind has made the plane drift well to the right of the centerline. To correct, he cranks in more left aileron to steepen his bank, and he adds up-elevator to accelerate his turn; both increase the centrifugal load. As the aircraft is realigned with the runway, the pilot applies heavy, right aileron to straighten up. The down-aileron (left) wing stalls, and over he goes to the left as the plane starts to spin. Unable to recover at this altitude, he becomes another statistic.

In an attempt to remedy the spin/stall syndrome, a variety of wing modifications were tested by

Figure 1.
Classic stall/spin flight path, frequently fatal. Wrong way to "hit" the runway.

The Osprey, powered by a .45 diesel, about to start its takeoff run. The leading-edge droop shows clearly.

aeronautical engineers: fixed or retractable LE slots; wing washout to reduce tip angles; greater camber at the wingtips and slot-lip ailerons. While modifications did improve stall behavior, they also aggravated spin characteristics. Many of these changes worsened aircraft performance and increased the complexity and cost of construction and maintenance.

NASA'S SOLUTION

In the late '70s, NASA's Ames Research Center initiated a program to develop an improved LE that would be inexpensive to manufacture and would require no maintenance. After determining the best wing modification through extensive wind-tunnel tests, NASA incorporated these design changes into an R/C scale model. Stall/spin characteristics were significantly improved, and, to confirm these R/C model results, four, full-scale light aircraft—a Grumman American Yankee, Beech Sierra, Piper Arrow and Cessna 172—were modified and flown extensively.

Because manufacturers pay such high insurance premiums, they're building fewer, full-scale light airplanes. Verilite Aircraft Co. Inc. has developed a new design that incorporates NASA's LE modifications. The Sunbird (Figure 2) is the first aircraft designed to provide spin resistance and thereby reduce stall/spin accidents. NASA has run extensive wind-tunnel tests on this aircraft, and it has built and tested a small scale model, a ¼-scale R/C model and a full-scale version. A 28-degree AoA was recorded before the stall was encountered.

On the previous page, a photo of my Snowy Owl (one of my earlier models) is in slow-speed flight with its flaps extended. The increasing LE droop ahead of the ailerons is clearly visible, and it reached its maximum at the wingtips. This modification succeeded in delaying the stall, but the ailerons proved ineffective in the attitude shown.
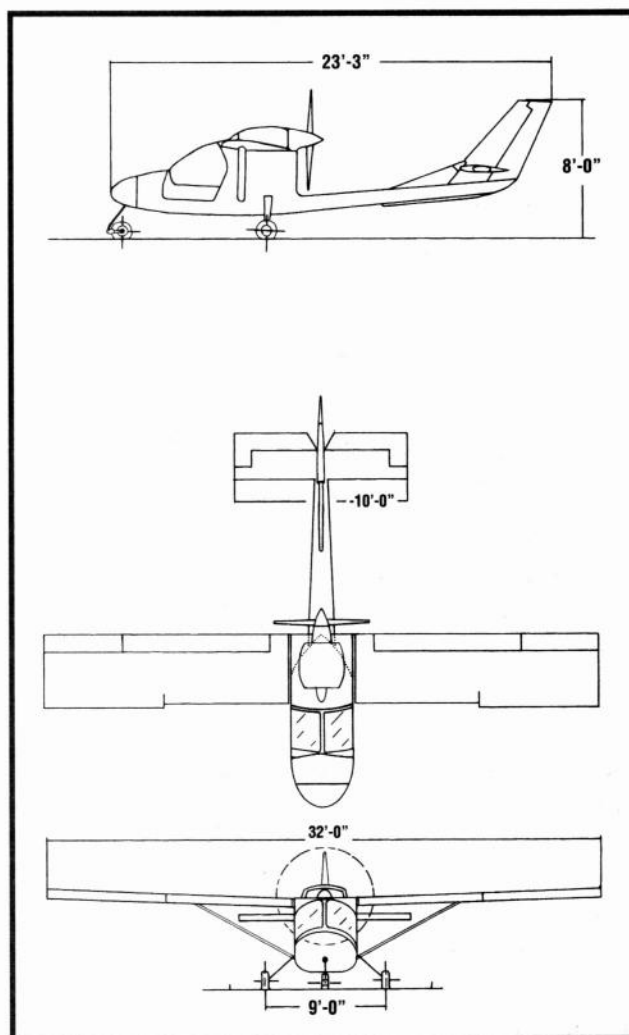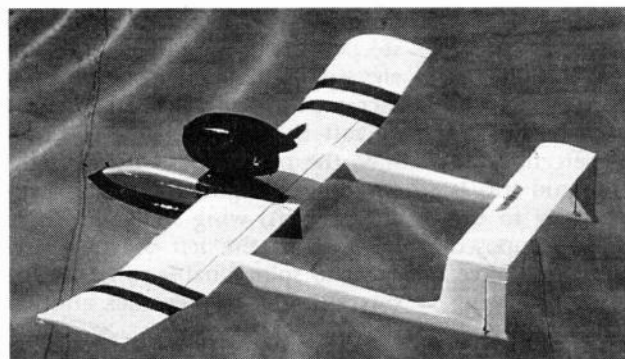

Figure 2.
Verilite Aircraft Co. Inc. Sunbird.

The Sea Loon in its natural element—water. The leading-edge droop starts at the inner-wing stripe.

NASA's LE droop has been successfully incorporated into seven R/C model aircraft: the .15-powered Sparrowhawk; the .40-powered Snowy Owl II; the .15-powered Sea Loon (a flying boat); the Swift; the Seagull III; the Seahawk; and the Osprey, which is a .45-powered craft designed to be used with both wheels and floats.

While the smaller models can be *forced* to spin, only one or two turns are achieved before the spin becomes a spiral dive, and recovery is instantaneous when the controls are neutralized. Aileron control is greatly improved in the stall, with the flaps up or down. Despite many attempts, I haven't been able to spin the larger models.

As the illustration of the airflow over the NASA wing shows, the outboard, drooped panels become very

Figure 6.
NASA droop (cross-hatched areas) on various airfoils.

the cross-hatched section, and a light LE spar. Cover them with bond paper or thin balsa, and glue this unit to the outboard wing LE. I haven't tried this droop on symmetrical airfoiled wings, but it might delay the stall in both upright and inverted flight (see Figure 6C).

Congratulations, NASA, for your major contribution to aviation safety. I hope this "safe" wing will be incorporated in future aircraft designs. ▲
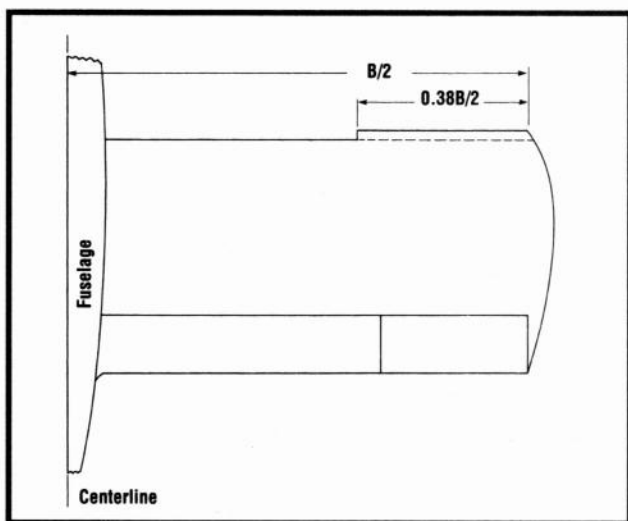
low-AR wings, with a stall that's considerably delayed. The droop itself, which delays the stall to approximately twice the stall angle of the basic wing, permits effective aileron control at the higher AoAs.

If you fly models with flat-bottom or semisymmetrical airfoils, you could modify the wings by adding droop. (See the cross-hatched areas in Figure 6 A and B). For evaluation purposes, I've done this by using Styrofoam, which is held in place with transparent tape.

As an alternative, you could add balsa ribs like the ones shown in

Figure 7.
The wing planform showing the proportions of the added leading-edge droop. Note that the corners formed by the inboard end of the droop must be sharp where the droop addition meets the normal airfoil.
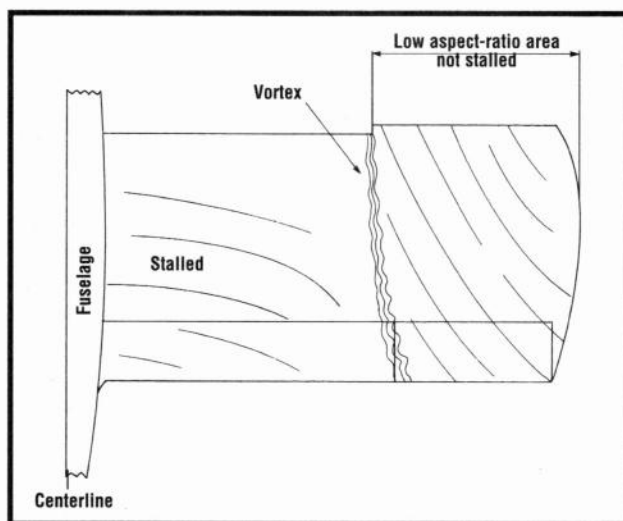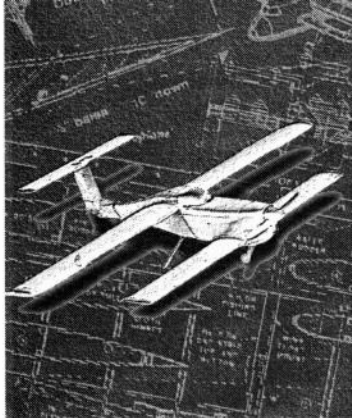

Figure 8.
The airflow over the NASA wing at high angles of attack. While the inboard, undrooped section is stalled, the sharp-cornered notch in the leading edge produces a chord-wise vortex that effectively separates the two areas.

Chapter 16

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Landing-Gear

Design

The landing gear of a propeller-driven aircraft has two major functions. The first is to provide adequate clearance between prop tips and the ground. The second, and no less important, is to permit the plane to rotate on both takeoff and landing so that the wing's AoA comes close to the stalling angle of its airfoil. At that AoA, the wing is near the airfoil's C_L max. This permits the lowest landing and takeoff speeds of which the model is capable.

On the ground, however, it should not be possible to rotate to or beyond the wing's stalling angle. Such a stall on takeoff or landing could be damaging, both to the model and to its designer's ego!

For windy-day flying, good judgment dictates flaps-up landings, and at a lower AoA for good control. The wind's speed reduces the model's ground speed accordingly.

This chapter deals with the landing-gear function. Intelligent determination of the AoA for landing
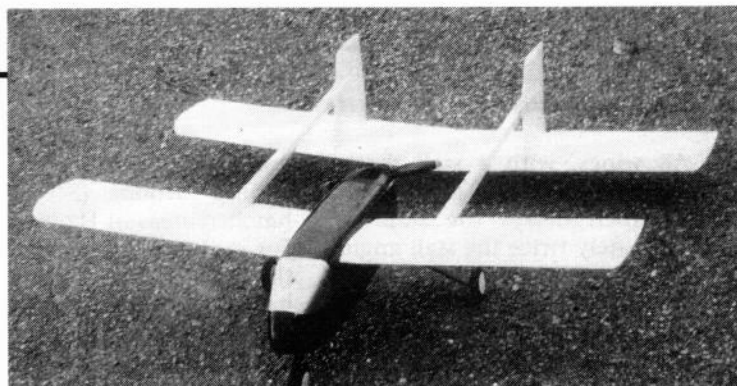
The Wasp tandem wing. The prop's position, just behind the main landing gear, has no clearance problem.

and takeoff requires consideration of the following:

■ The airfoil's characteristics and the Rn at landing and takeoff speeds.

■ Adjustment of "section values" to those for your wing's AR and planform.

■ The effect on the stalling angle of flaps when extended.

■ The impact of ground effect.

■ The wing's AoA in level flight. If that angle is 3 degrees and the land-

Figure 1.
Airfoil data for Eppler 197.

(University of Stuttgart,

ing/takeoff angle is 12 degrees, then the plane has to rotate through only 9 degrees to reach the 12-degree angle.

■ Wings incorporating the NASA "droop" will have an increase in landing/takeoff angles.

LANDING GEAR

For conventional models, the wing characteristics control the landing/takeoff AoA. For canard or tandem-wing models, lift is generated by both wings. Well-behaved canards or tandem wings have front wings that must stall first, so that for landing-gear design, only the fore-plane's characteristics are to be considered, not the aft wings.

Now, about those six factors: Figure 1 provides the lift, drag and pitching-moment characteristics of the Eppler 197. On the left, C_L 1.1 has been selected as the takeoff/landing C_L at an 8-degree AoA. This is well below this section's stalling angle of 16 degrees, and the stall is gentle with no hysteresis. Figure 1 of Chapter 14, "Design for Flaps," gives the additional lift coefficient that slotted flaps develop.
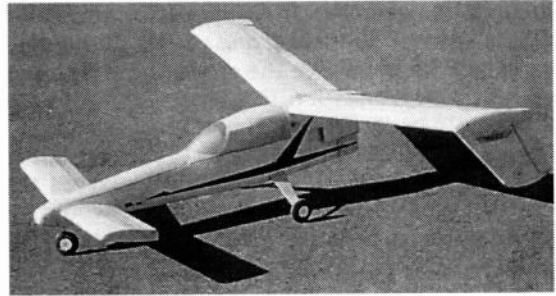
If you know (or can reasonably estimate) your model's wing loading in ounces per square foot, and if you calculate your wing's "close" to C_L max., as above, with slotted flaps deployed 20 degrees for takeoff and 40 degrees for landing, Figure 3 of Chapter 3, "Under standing Aerodynamic Formu-las," will provide the means to estimate both landing and takeoff speeds in mph. With the Rn under your belt, select the appropriate Rn curves of your airfoil. Note that Figure 1 offers different curves for different Rn numbers. For E197, lift is little affected, but profile drag increases at low Rn.

SECTION VALUE ADJUSTMENTS

The values in Figure 1 are called "section values" and are for "infinite AR." A model's wing has

a "finite" AR and wingtips. In addition, the wing's planform (straight or tapered) has an impact. The formula previously discussed in Chapter 3 will help you to adjust the wing's AoA to provide the lift coefficient selected and compensate for both AR and planform.

Using the data in Figure 1 and noting that the E197 airfoil starts to lift at minus 2 degrees and achieves C_L 1.1 at plus 8 degrees, the section AoA would be 10 degrees. Using an AR of 6 (this depends on your design, of course), the total AoA equals 13.91 degrees. Let's say 14 degrees—less the minus 2 degrees (since it starts lifting at minus 2 degrees), or 12 degrees for the horizontal.
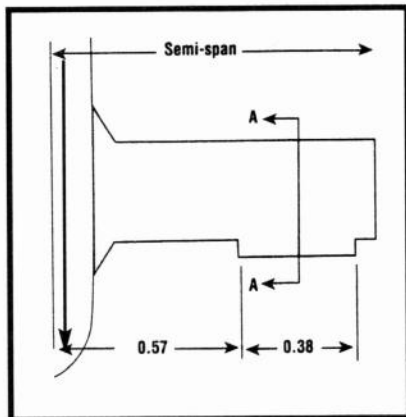
Summary: our AR 6 straight-wing with airfoil E197 would require a 12-degree AoA to achieve C_L 1.1.

The Canada Goose Canard's tricycle landing gear. Propeller clearance on takeoffs and landings is critical for rear-engine canards.

HIGH-LIFT DEVICES

Slotted flaps reduce takeoff and landing AoAs (as shown in Figure 7 of Chapter 3). A 20-degree flap deflection causes a reduction of 1 degree, but for the full 40-degree deflection, it is 4 degrees. Since landings are more critical than takeoffs, use 4 degrees. As one former jet fighter pilot puts it, "Takeoffs are optional; landings are unavoidable."

GROUND EFFECT

This phenomenon starts at half the model's wingspan above the ground (or water) and becomes more intense closer to the ground. Both landings and takeoffs, hence, are made in "ground effect." It acts like a substantial increase in AR. A reduction in the stall AoA and in
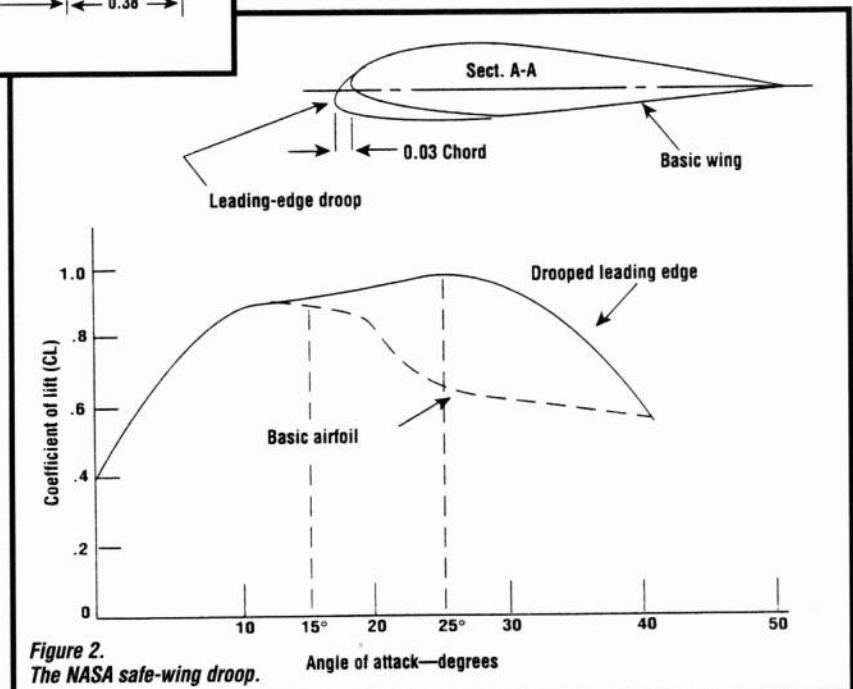
Figure 2.
The NASA safe-wing droop.

induced drag results. For a model with a span of 60 inches, *and* with its wing 8 inches above the ground on touchdown *and* AR 6, this reduction would be 10 percent of our 12-degree AoA, or 1.2 degrees.

Using the Swift as an example, the wing's AoA for level flight is zero degrees, so no adjustment for a positive AoA is called for.

NASA SAFE-WING DROOP
This is recommended for sport models (see Figure 2). It delays tip-stalling and provides effective aileron control in the stall. Since the droop occupies 38 percent of the semi-span, it is estimated that it provides a full 4 degrees more in the takeoff/landing AoA.

Summary: the adjusted AoA for C_L 1.1 of airfoil E197 is 12 degrees; slotted flaps reduce this by 4 degrees; ground effect makes a further reduction of 1.2 degrees; and the NASA droop adds 4 degrees for a net AoA of 10.8 degrees.

For the Swift, this was increased slightly to 11 degrees to provide a 2-inch prop-tip ground clearance with a 10-inch-diameter prop. The Swift illustrates the benefit of a high thrust line provided by an inverted engine (see 3-view in Chapter 26). If the engine was upright and still fully cowled, the thrust line would be lowered by roughly 2 inches. A landing gear 2 inches longer, to preserve the 2-inch ground clearance, would be necessary. This could entail a substantial increase in the "tail angle," bringing the wing's AoA to above

the stall for takeoffs/ landings.

The remedy would be to lower the aft fuselage to reduce the tail angle so as to avoid the stall. This would affect spiral stability as discussed in Chapter 9, "Vertical Tail Design and Spiral Stability." The longer gear would increase both weight and drag.

THE "CRANE" II
The Crane II, a STOL model, had a very nose-high landing posture. It had an 11-inch-diameter variable-pitch prop; full-span LE slots and slotted flaps. Spoilers on the wing's upper surface provided roll control. The horizontal tail had an inverted and LE-slotted lifting airfoil to provide the high tail download that is needed to achieve the very high AoA (20 degrees) provided by the wing's slots and flaps.

The Crane II had a fueled weight of 101.5 ounces and a wing loading of 22.75 ounces/square foot; power was a .45 engine; power loading was 225 ounces per cubic inch or engine displacement (cid).

POWER LOADING
Power loading in ounces per cubic inch of engine displacement is a useful "rule of thumb" for evaluating the weight-to-power relation-
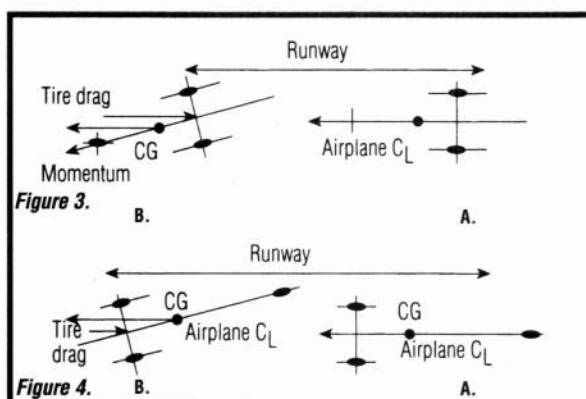

Figure 3. The dynamics of tricycle landing gear. WIth the CG ahead of the main gear, the inertia of the CG tends to keep the model moving straight forward. Figure 4. The dynamics of tail-dragger landing gear. With the CG behind the main gear, the inertia of the CG tends to exaggerate any divergence from a direct path straight forward.

ships of 2-stroke or 4-stroke models, but not 2-stroke versus 4-stroke.

The formula is simple:

$$\frac{1 \times gross\ weight\ (oz.)}{engine\ cid} = power\ loading$$

A trainer that weighs 80 ounces and is powered by a .40ci 2-stroke engine would have a power loading of 1 divided by .40 x 80 = 200 ounces/cid. The crane's power loading of 225 ounces/cid with a 2-stroke engine shows that it has greater weight for its power than the trainer.

CG AND LANDING GEAR
The CG location, in both the horizontal and vertical senses, is the focus around which the landing-gear geometry is established. For model aircraft, the only cause of a CG shift during flight is the reduction in the weight of the fuel as the flight progresses. For a conventional model, this causes a rearward shift of about 3 percent of the MAC. For a rear-engine canard, the fuel tank is typically behind the CG so that a similar, but forward, CG shift occurs. The vertical CG location is usually "eyeball" estimated. It is better to get it a bit higher than lower.

There are two major types of landing gear:

■ **Tricycle.** The CG is ahead of the main wheels, and the nose wheel is steerable.
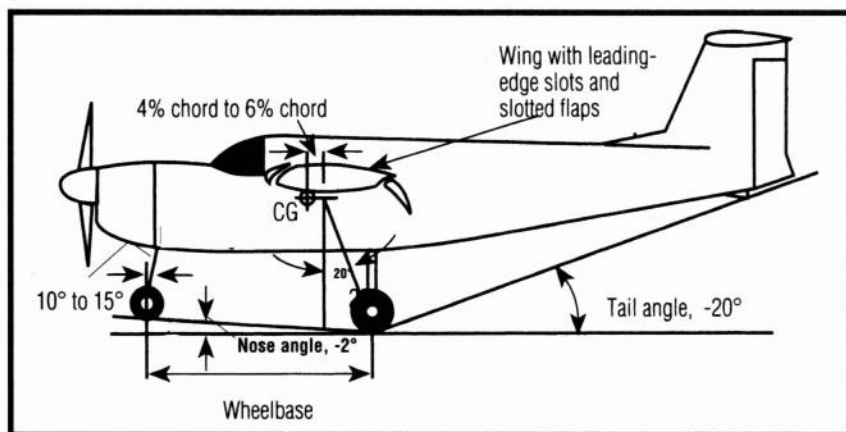
■ **Tail-dragger.** The CG is behind

Figure 5.
Fuselage upsweep required to obtain a high tail angle and a short landing gear. This drawing shows the Crane, which was designed by the author.
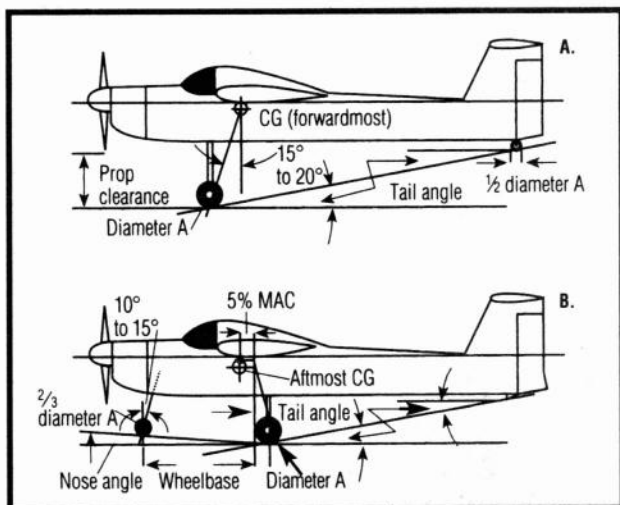
Figure 6.
The geometry of tail-dragger landing-gear design (above) and tricycle landing-gear design.

the main wheels, and the tail wheel is steerable.

Bicycle landing gear is a variant of tricycle gear; a single rear wheel replaces the normal tricycle main wheels; the front wheel is steerable, and tricycle geometry applies.

The single-wheel CG of some sailplanes is a variation on tail-dragger style and geometry. The high tail angle is not needed because there is no prop, and these gliders land in a nearly horizontal attitude.

LANDING-GEAR DYNAMICS

■ **Tricycle gear.** On the landing or takeoff run, tricycle landing gear—with the CG ahead of the main wheels—is self-correcting directionally (see Figure 3). The nosewheel steers, prevents the plane from "nosing over" and protects the propeller.

When a "trike"-geared model tips backward so that the tail skid rests on the ground, the CG rotates with it. If this rotation brings the CG behind the wheel axles, the model will stay tail-down—a most undignified posture! Shifting the landing gear rearward from the CG by 5 percent of the MAC, as shown in Figure 6, prevents this from occurring.

Most trikes sit with their longitudinal center line parallel to the ground. A nose-down angle of 2 to

3 degrees, as shown in Figure 6, is suggested. On landing, after the nose-wheel has made contact with the ground, this nose-down angle will bring the wing close to its angle of zero lift. The model will tend to cling to the ground. The potential for nose-gear damage is reduced, and experience has proved that this nose-down attitude has no adverse effect on takeoffs.

Figure 9 illustrates the trike geometry for a rear-engine canard such as the Canada Goose. Obviously, a very high thrust line is needed to avoid the need for an unduly long landing gear for prop-tip protection. The Swan canard illustrates this point. For such craft, add 5 degrees to the tail angle.

Figure 5 shows how fuselage upsweep may be used to reduce the length of the landing-gear legs for models that require large tail angles, such as the Crane.

This high tail angle moves the wheel axles farther behind the CG and requires heavy up-elevator deflection to rotate the model for takeoff; but as the tail goes down, the wing's lift ahead of the CG aids the model's rotation for quick takeoffs.

■ **Tail-draggers.** As soon as a tail-dragger's speed, on takeoff, permits the tailwheel to lift off, it becomes directionally unstable (Figure 4). The CG wants to get ahead of the main wheels (see "B" of Figure 4). Coarse

rudder application is needed for directional control on takeoffs and on landings.

As the tail comes up, propeller torque and gyroscopic precession cause the model to veer. Compensating rudder is applied until the aircraft is just airborne.

If liftoff is forced by heavy up-elevator action, the model has ample dihedral and coarse rudder is still applied, a sudden snap roll may occur. Unless your reflexes are very quick, a damaging and embarrassing crash will occur. It has happened to this author!

Another disadvantage of a tail-dragger is its tendency to nose over, which is hard on props! Moving the wheels farther forward to reduce this tendency aggravates the model's directional instability on the ground. To avoid nosing over, taxiing, particularly on grass, should be done holding full up-elevator.

DETAIL DESIGN

Figure 6 illustrates the procedure for positioning the main landing-gear wheels for both trikes and tail-draggers. Take the tail angle described previously and, on a side
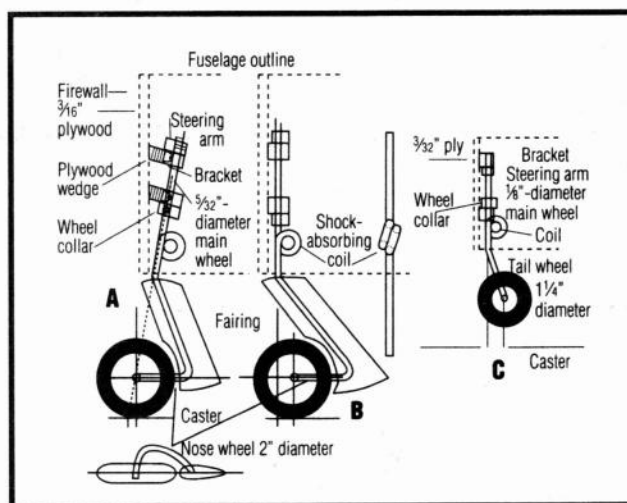

Figure 7.
Nose- and tail-gear detail (two arrangements for a nose wheel and one for a tail wheel).

view of your design, draw a line *that defines the tail-angle to the horizontal*, originating either at the tailskid or at the tail wheel.

■ **Tricycle gear.** To prevent the model from sitting back on its tail,

follow this procedure. Draw a vertical line through the point that is 5 percent of the MAC behind the CG. Draw a second line through this point that defines the tail angle to the vertical line just drawn (see Figure 1). Notice that this tail angle is the same one as that defined by the line drawn from the wheel to the skid. Where these two tail-angle lines intersect, draw a horizontal line forward to the nose-wheel position, and then draw a short vertical line upward from the same intersection. The main wheel axles should be on the short vertical line, with the wheels' outside diameter resting on the horizontal line. Decide whether a nose-down angle is to be used, and if it is, draw the nose angle at 2 to 3 degrees to the horizontal line. Nose and tail gear will be discussed later.

■ **Tail-dragger.** Draw a line at 15 to 20 degrees from the CG, in front of the vertical, as in Figure 6A. Where the two lines intersect, draw both horizontal and vertical lines. The main wheels' outside diameters should rest on the horizontal line, with their axles on the vertical.

TREAD WIDTH
Both trike and tail-dragger landing gear should have a lateral spacing ("tread width," or the distance between the centerlines of each tire) of 25 percent of the wingspan of an AR 6 wing (see Figure 8).

If the wing has a higher AR, calculate what the span would be for

AR 6 with the same area. The formula for AR equals span squared divided by the area. Knowing that the AR is 6, the imaginary span can be easily calculated; the wheel-tread dimension will be 25 percent of that span.

STATIC LOAD SQUAT
Models with music-wire or aluminum landing-gear legs originating in the fuselage and sitting on the ground bearing the model's gross weight (iG) will "squat." For .40 to .50ci-powered models, this squat is about ½ inch and reduces the tail angle for takeoff. To compensate, reduce your landing gear legs' "included angle" (see Figure 8) to lower the wheels and compensate for the squat.

WHEEL DIAMETER
Smaller wheels have less air drag. For paved runways, a 2-inch diameter is the recommended minimum; for grass, a 2¼- to 3-inch diameter is suggested.

NOSE- AND TAIL-WHEEL DESIGN
Steerable nose- or tail-wheel gear should incorporate a modest amount of caster. A modest amount of offset, as in the case of a grocery-cart caster wheel, facilitates steering. Similarly, in the case of landing gear, such gear tracks well and permits easy steering. Too much offset invites "shimmy." An offset of 20 percent of the wheel's diameter is sufficient. Figure 7 illustrates two
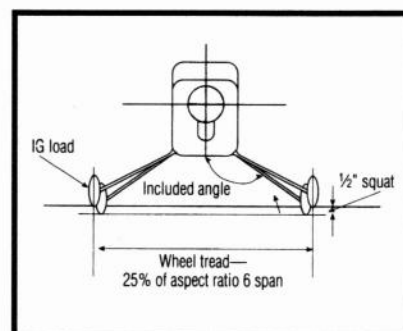
Figure 8.
Wheel tread and squat detail.

nose-wheel arrangements (A and B) and one for a tail wheel (C).

The nose-wheel gear is mounted on the rear surface of the ply engine-mount bulkhead. For a conventional design, this determines the position of the nose gear. For a canard with a rear engine, the nose wheel should be well forward, as in Figure 9. Note that, in Figure 7, A and B, the shock-absorbing coil is totally enclosed in the fuselage to reduce drag.

For tail-draggers, this author prefers a somewhat forward tail-wheel location, with the tail-wheel leg supported internally by nose-wheel brackets bolted to plywood, as in Figure 7C.

MAIN LANDING-GEAR LEGS
Main landing-gear legs should be a continuous piece of metal from wheel to wheel so that bending loads do not have to be absorbed by the fuselage structure, but are contained in the landing-gear legs themselves. ▲
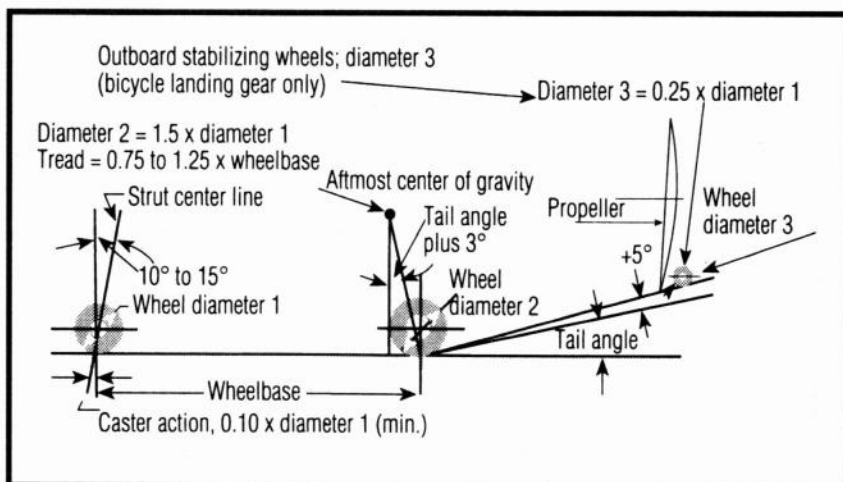
Figure 9.
Layout geometry for tricycle or bicycle landing gear for a pusher canard.
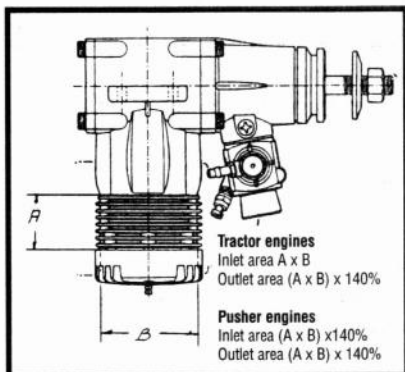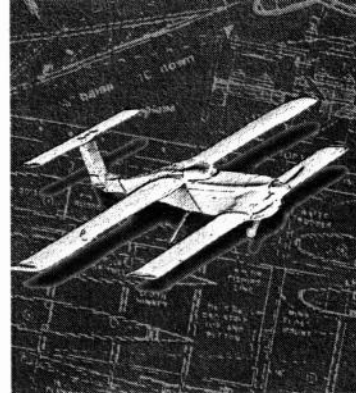
Chapter 17

Figure 1.
Sizing cooling-air inlets and outlets.

O ur model airplane engines, by themselves, are beautiful, powerful examples of precision machining and engine technology.

Hung on the front of a model airplane and left uncowled, they are hideous from a drag point of view. Even when partially cowled but with the cylinder sticking out, they make a model look like a full-scale Cessna 172 with a garbage can above the engine just behind the prop–ugly!

A well-designed cowl greatly reduces drag, improves a model's appearance and actually improves engine cooling. Why are there so few cowled engines among the

many models, both kit-built and original designs, at our flying fields? This author surmises that there are three major objections:

■ Removing a cowl to service the engine is a nuisance to be avoided. In most cases, it is necessary to remove the spinner, the prop, the needle-valve needle and up to a half-dozen small, easy-to-lose screws. Replacement reverses this boring sequence.

■ Cowls are difficult to make.

■ Fear that a cowled engine will not be adequately cooled.

The design, construction and fastening of the cowls described in this chapter responds to and overcomes all three objections:

■ The removable portion of each cowl described is almost ridiculously easy both to remove and to replace. Taking off the spinner, the prop and the needle-valve needle is unnecessary, and there are no screws to laboriously unscrew (and lose). The engine is easily accessible for servicing.

■ Such a cowl is easy to make, as this chapter will demonstrate.

■ Cooling is adequate, as proven by test runs on hot summer days at full rpm with the model stationary and consuming full tanks of fuel.

DUCTED-COWL DESIGN

For minimum drag, the cooling-air entry should be as small as possible, yet large enough for adequate cooling. Bear in mind that only the air that actually contacts
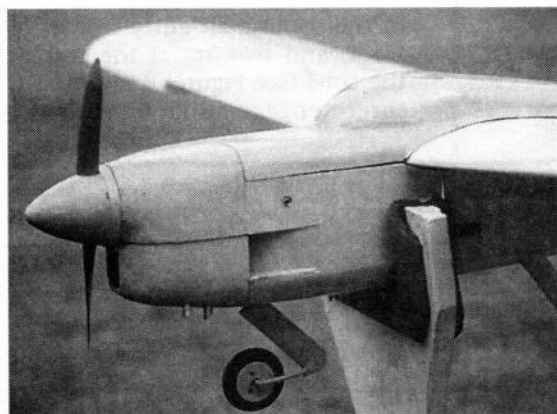
Ducted-Cowl Design

the cylinder and muffler does the cooling. Air passing 1 inch away from the cooling fins does nothing.

A good, low-drag cowl design requires:

■ An inlet;

■ an expanding chamber, or "diffuser";

■ the item to be cooled: radiator, or cylinder and muffler;

■ a contracting part, or "nozzle(s)"; and

■ outlet(s) into the passing air stream at point(s) of low air pressure.

Prop-driven air enters the diffuser, slows down, cools the cylinder and muffler, expands because of the heat

Figure 2.
Cowl top view—internal muffler.

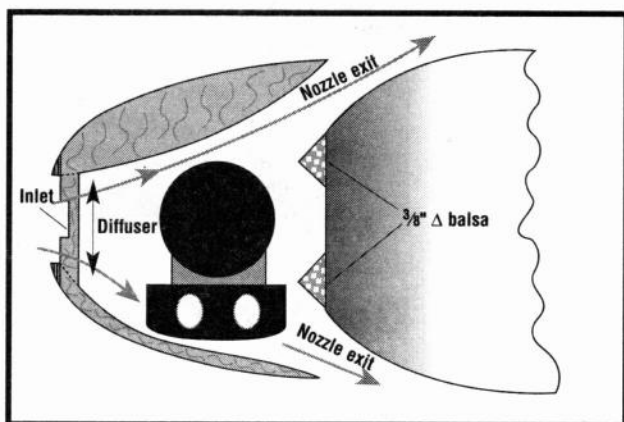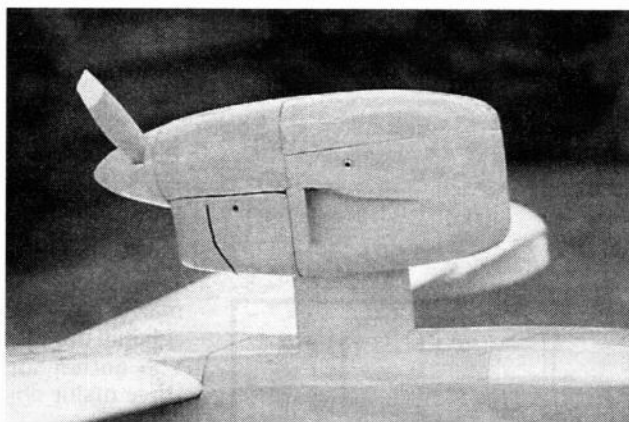*The Swift's cowl; note the jack location.*

Figure 3.
Cowl section A-A (see also Figure 6—internal muffler).

The pusher nacelle on the Seagull III flying boat. The NACA inlet and the outlet below the spinner show.

absorbed, speeds up in the nozzles and exits at considerable velocity. British WW II Hurricane fighters' ducted-engine coolant radiators were based on these principles; they contributed thrust, not drag. The hot, expanded air exiting the duct's nozzle provided some jet-like propulsion. This is not to suggest that these cowl designs will contribute thrust, but there will certainly be substantial drag reduction.

INLET AND OUTLET SIZING—TRACTOR ENGINES

Figure 1 shows the side view of a model engine. An empirical rule of thumb, based on experience, is to provide an air-entry area that's equal to the area of the finned portion of the cylinder, as shown. Whether the opening is round, square, or rectangular makes no difference provided the entry has the area described.

The cooling air exit(s)' rule of thumb is that the total exit area be 140 percent of the entry area. For example: an entry area of 1.25 square inches requires an exit of 1.75 square inches for one, or 0.875 square inch each for two exits.

ENGINE AND ENCLOSED MUFFLER

Figure 3 shows a horizontal cross-section through the Swift's cowl with a muffler. Both the engine and the muffler are wholly enclosed. It has an inlet, a diffuser, a cylinder, muffler and nozzles; and the exits are at points of reduced air pressure on the fuselage sides (they look like gills on a fish!). The fuselage must be widened to accommodate the engine and muffler as in Figure 3.

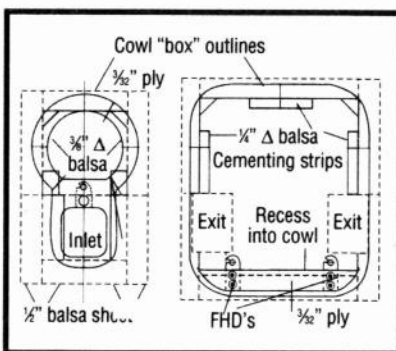The "teardrop" fuselage was described in Chapter 12, "Improve Performance by Reducing Drag."

Figure 4.
Spinner ring/entry and rear hold-down detail.

This type of fuselage lends itself to a wider forward section without a drag penalty. Figures 3 and 6 detail the cowl installation.

Exhaust stacks may extend through the cowl, and the necessary holes must be elongated sideways $1/8$ inch for cowl removal. They may also end just clear of the inside of the cowl with slightly larger, round holes.

ENGINE AND EXTERNAL MUFFLER

Figure 7 shows the cross-section of a cowl for an engine equipped with a stock muffler. While the muffler (and pressure tubing to the tank) is exposed, its drag is largely overcome by the jet-like exhaust gases squirting backward. With an external muffler, the fuselage may be narrower, as shown.

COWL FASTENING

The removable portion of the cowl is held in position by three "flat hold-downs" (FHDs). One is in the cooling air-entry former in front, and two are at the rear of the cowl (see Figures 4 and 6). All three engage no. 2 shoulder
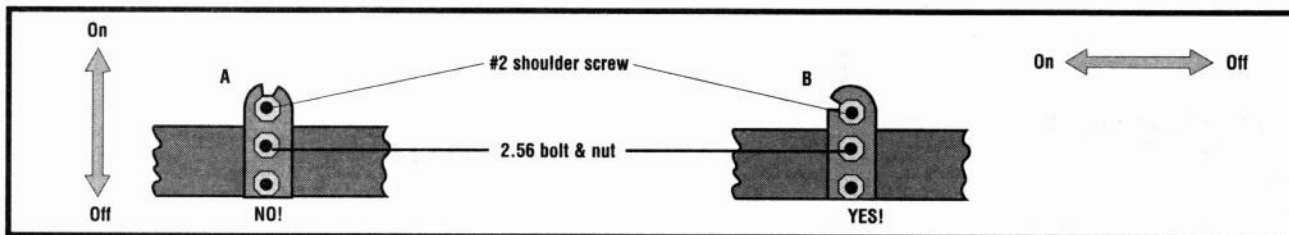

Figure 5 A and B.
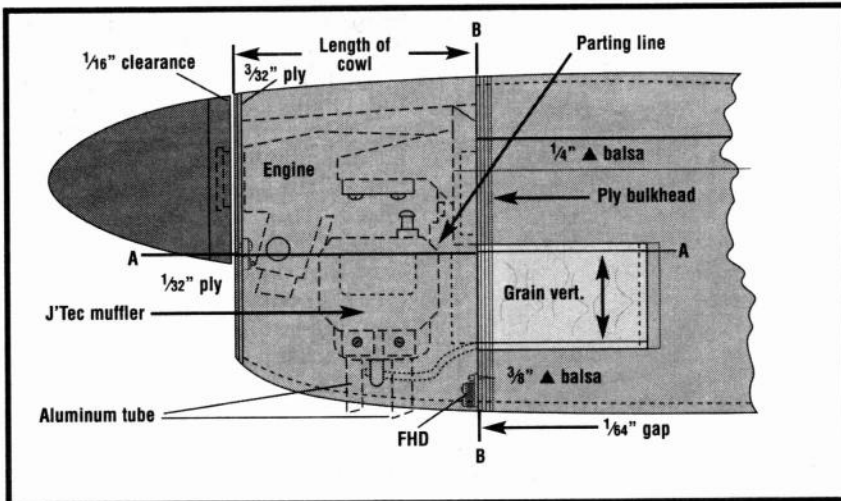*Goldberg flat hold-down (FHD) installation.*

Figure 6.
Cowl side view—tractor engine; internal muffler.

either just above or just below it. Obviously, a suitable slot or slots (half above and half below the parting line) is essential to clear the needle.

If an external muffler is used, then suitable cutout(s) must be made to clear the portion from the engine exhaust to the muffler. In Figure 9, note the 1/32-inch plywood parting-line separator that guides the shaping of the cowl both inside and outside. It is firmly cemented to the removable portion of the cowl.

ASSEMBLY AND SHAPING

Photo A shows balsa sheet, tri-stock and plywood components partially assembled into the cowl's two parts. Carefully trim the length of both parts of the cowl's balsa to suit the length of your installation, as shown in Figure 6.

At this stage, the fuselage should be finished (but not covered). Temporarily install the engine (less the needle-valve needle) and muffler on the engine mount so that the cowl can be shaped inside as shown in the photos and drawings. The ply parting-line separator guides this effort. A Dremel sanding drum and drill will do this quickly and easily.

The cowl structure around the crankcase requires only minor internal contouring to clear the muffler; the removable portion needs considerably more internal shaping to clear the cylinder and muffler.

The three flat hold-downs are both CA'd and bolted (2-56 bolts

screws; two are screwed into the plywood engine bulkhead, and one into the plywood spinner ring.

Initially, this author used these FHDs as shown in Figure 5A. A knife blade inserted at the parting line and then twisted, detached the cowl. On smaller models, this method was satisfactory. On larger models—and after losing several detachable portions in flight (none was ever found despite lengthy searches)—it was evident that this form of cowl attachment was unsatisfactory. It was belatedly realized that the wrong end of the FHDs was being used, and the arrangement shown in Figure 5B was employed very satisfactorily—no more lost cowls!

A useful byproduct of this change was that removal requires only a sharp knuckle rap on the removable portion's side opposite the muffler. Replacement requires the alignment of the "hooks" on the FHDs with the shoulder screws and a rap on the cowl's muffler side. It is amusing to have a startled onlooker exclaim, "How did you do that!"

CONSTRUCTION HINTS

Over the years, I have designed and built many types of cowl. They ranged from laboriously hollowed-out solid balsa to fiberglass-and-epoxy lay-ups on dissolvable foam mandrels. The ducted-cowl con-

struction described previously has been used on at least seven model designs. The sound-deadening properties of thick balsa sheet are a definite advantage. In this chapter, I will give more details on ducted-cowl construction and also touch on design considerations for a cowl mounted in a pusher configuration.

That portion of the cowl behind the spinner and surrounding the engine crankcase is solidly CA'd to the engine bulkhead. The other, removable, portion surrounds the cylinder. The level of the parting line between these two parts is important. It must be horizontal, and it must separate through the center of the needle-valve needle—

Figure 7.
Cowl section A-A; external muffler.

Figure 8.
Cowl box detail; 1/2-inch balsa sheet; internal muffler.

the fuselage contour, as shown in Photo C.

Next, remove the cowl and take the engine and muffler off the motor mount. Epoxy the rear FHD ply assembly in the removable portion of the cowl as shown in the photo. This requires some trimming of both the ply and the balsa. Note that the open side of all three FHD's "hooks" should face away from the muffler side.

Now clamp the cowl into position as you did before, carefully aligning it with the spinner and fuselage. Through the air-entry hole, using the rear flat hold-downs as guides, mark the positions of the no. 2 shoulder screws on the engine bulkhead. Remove the cowl, drill 1/16-inch holes in the bulkhead, put some CA in the holes, and install the two screws.

and nuts) to their plywood parts. (Note the bolt-orientation nuts inside.) File the round bolt heads level with the bottom of the screwdriver slot after they've been installed in the plywood.

Install and lightly tack-glue the cowl "box" to the engine bulkhead as shown in Photo B, with the spinner ring cooling-air entry assembly cemented to both portions of the cowl.

Using an old spinner backplate of the correct size, clamp the box into position by installing the prop nut and washer, putting a 3/32-inch balsa-sheet spacer between the spinner backplate and the ply spinner ring.

Shape and sand the outside surfaces to match the spinner; the cooling-air entry plywood parting line; the 1/32-inch ply separator and
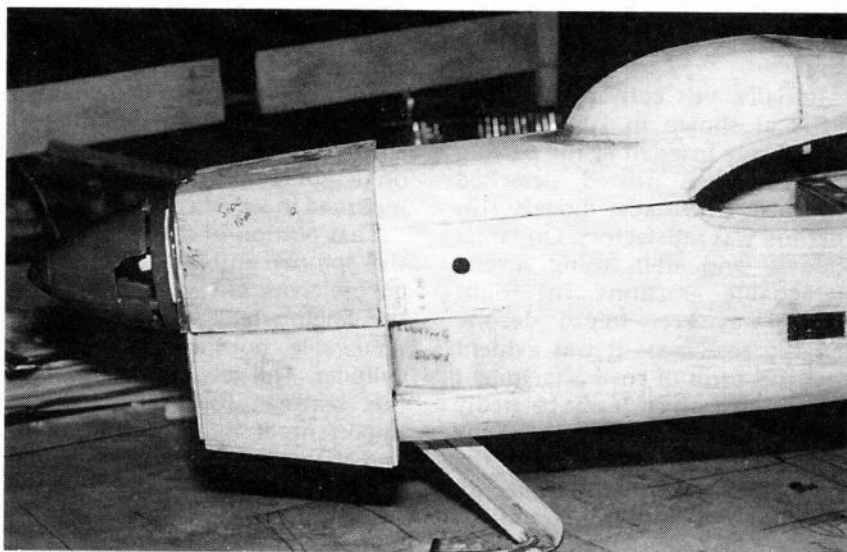

Photo B.
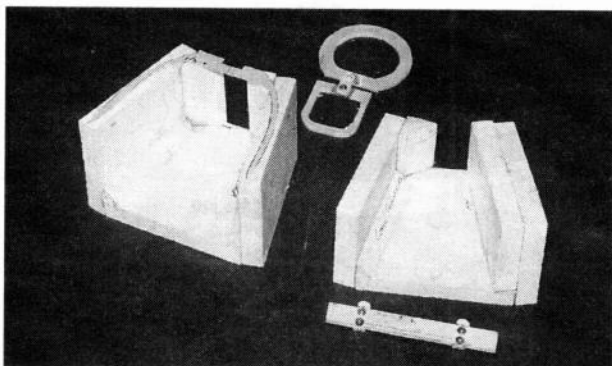*The cowl "box" has been clamped into position for external shaping.*

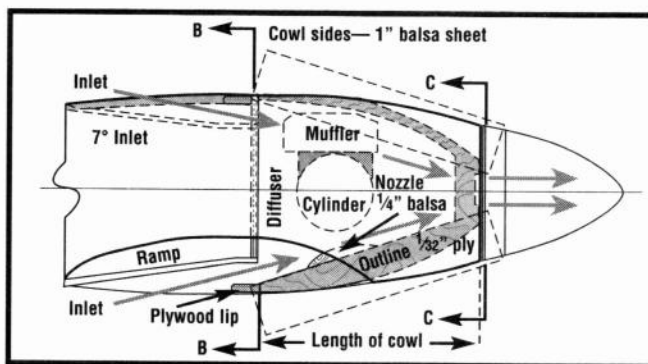

Photo A.
Cowl components are shown partly assembled.
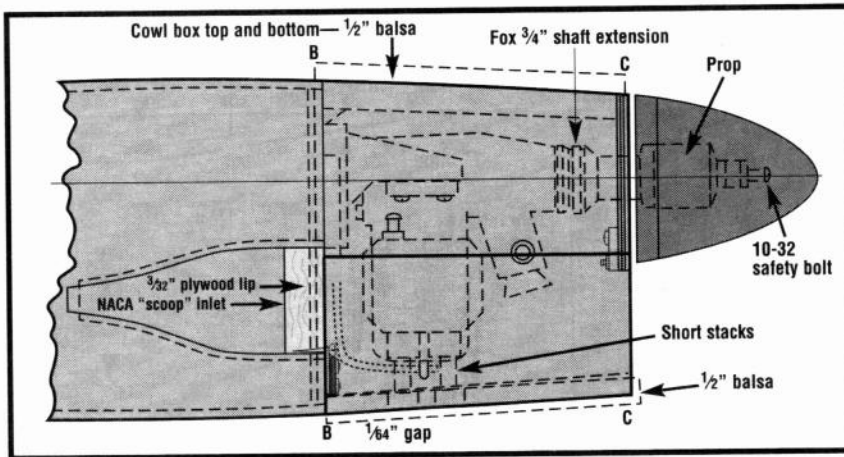

Figure 9.
Top view of pusher engine cowl.

Figure 10.
Side view of pusher engine cowl.

Cowl box top and bottom— ½" balsa
Fox ¾" shaft extension
Prop
B
C
10-32 safety bolt
3/32" plywood lip
NACA "scoop" inlet
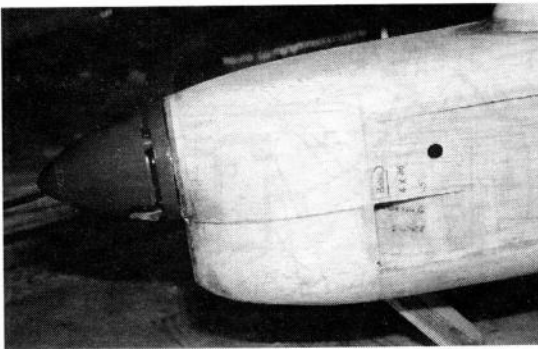Short stacks
½" balsa
B 1/64" gap C

Photo C.
The shaped and sanded cowl. The upper portion has been CA'd to the engine-mount bulkhead.

Permanently install the engine and muffler, connect the carb-to engine-servo linkage, replace the needle-valve needle, install the fuel and muffler pressure tubing from the engine to the fuel tank, and connect the glow-plug clip to the glow plug.

Solidly CA the fixed portion to the engine bulkhead, and clamp the whole cowl into position as before, as shown in Photo C. In Photo D, both parts are ready for painting. The engine's accessibility is evident.
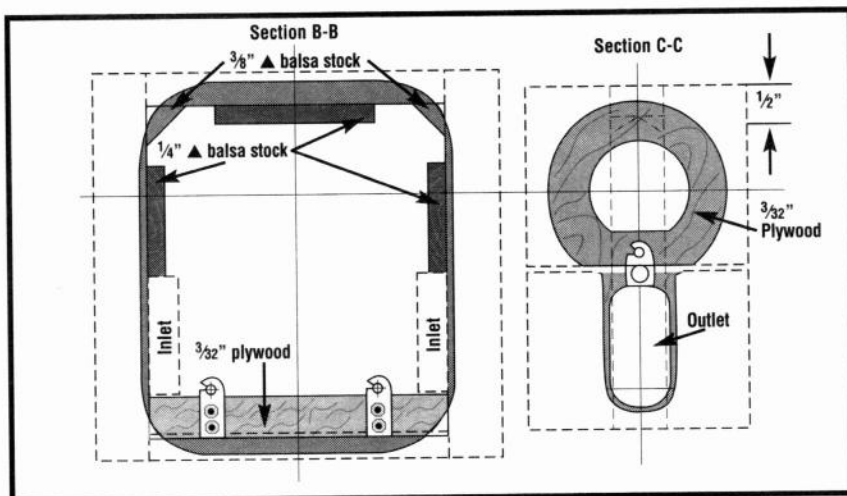
GLOW-PLUG ENERGIZING

With the engine enclosed, the glow plug is energized by means of a two-conductor, closed-circuit type, Radio Shack phone jack. To energize the plug, a mating, 1/8-inch, Radio Shack plug is wired to the external power source and inserted into the jack. This is a major safety feature because the jack may be located well away from that deadly, rotating prop for plug removal. Figure 6 details the bronze glow-plug clip that's easily disengaged from the glow plug when plug replacement is necessary.

The jack is mounted through a 7/32-inch-diameter hole in a small square of 1/16-inch plywood. Both are epoxied to the inside fuselage wall so that the jack's knurled nut projects through a 5/16-inch-diameter hole in that wall. Figures 12, 13 and 15 provide a wiring diagram and engine-servo detail for an "onboard" glow-plug energizing system that heats the plug in flight, but only at low rpm. The system ensures a reliable idle, particularly for 4-stroke engines.

ENGINE PRIMING

Priming a fully cowled engine is easy. Invert the model on your field box to bring the engine upright. With a squirt bottle, inject a few drops of fuel into the carburetor. If the carb is closed, the carb entry forms a small cup which, when filled, provides adequate priming. The cooling-air entry hole permits this method of priming without

Section B-B
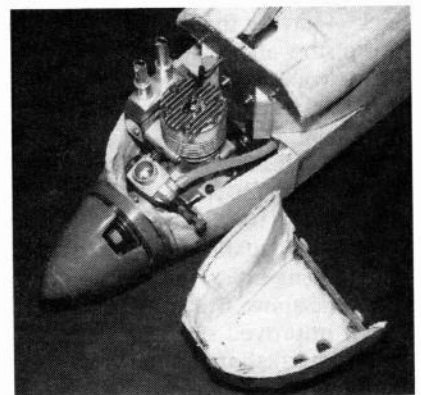3/8" ▲ balsa stock
1/4" ▲ balsa stock
Inlet
Inlet
3/32" plywood

Section C-C
½"
3/32" Plywood
Outlet

Figure 11.
Pusher engine cowl sections and hold-down detail (see Figure 10).

Photo D.
This cowl detail shows that servicing the engine is easy.

Figure 12.
Onboard glow-plug wiring diagram.

Figure 13.
Small engine servo (Futuba S33-S133).

Figure 14.
Details and ordinates of NACA submerged intake.

Table of ordinates	
X/L	$Y/\frac{w}{z}$
0	0
0.1	0.004
0.2	0.084
0.3	0.234
0.4	0.386
0.5	0.534
0.6	0.612
0.7	0.688
0.8	0.764
0.9	0.842
1.0	0.917

Figure 15.
Engine servo lengthwise in fuselage.

cowl removal. If, after a flight, the engine is stopped by closing the carb, subsequent engine starts don't require priming. To avoid "hydraulic lock"—having fuel trapped between the piston and the cylinder head—apply your electric starter with the model inverted (engine upright).

PUSHER ENGINE INSTALLATIONS
Figures 9, 10 and 11 show the pusher installation of the Seagull III—a flying boat. The engine sits in a nacelle above the hull.

For improved streamlining, a ¾-inch crankshaft extension was used, as shown in Figure 12. An enclosed muffler is mandatory, because the external muffler would exhaust the wrong way, facing for-

ward, and it could not be reversed, because that would foul the prop and prevent the propeller from rotating.

Cooling air enters the cowl through two, NACA-developed, low-drag, submerged air intakes recessed into the nacelle (or fuselage) sides ahead of the engine bulkhead. The combined areas of these intakes is the cylinder area described in Figure 1 plus 40 percent. The exit slot under the spinner has the same total area as the entries. The rotating prop "sucks" cooling air out of this cooling slot.

Construction, shaping and fastening the removable portion and glow-plug energizing are identical to the tractor installation.

NACA COOLING-INLET DESIGN
Figure 14 shows how to develop the shape of the NACA submerged intake. Note the intake width-to-depth ratio and the ramp floor at 7 degrees to the outside surface.

Over the years, I've used pusher engines cowled as described on five models. Cooling problems have not occurred.

Throughout this chapter, illustrations and photos show inverted engines (author's addiction). For upright installations, simply turn the photos and drawings upside-down! ▲

Chapter 18

Propeller Selection and Estimating Level Flight Speeds
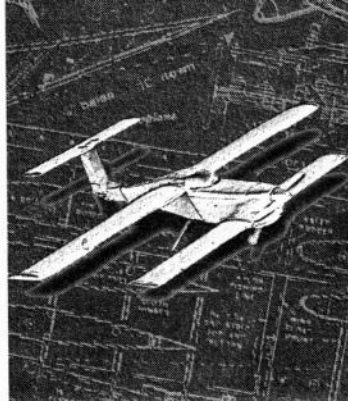
The wide variety of propeller makes, shapes, materials, diameters and pitches available today can be somewhat confusing. The choice of a prop to suit your model, its engine and your style of flying requires some understanding of how a propeller functions. It also requires an appraisal of the weight, wing area and aerodynamic drag of your airplane and of the power loading of the model—plus some insight into its engine's power characteristics.

In addition, the propeller's high-speed rotation leads to effects that every modeler should be aware of. These are:

- Slipstream;
- asymmetrical blade effect;
- propeller pitching moment;
- torque; and
- gyroscopic precession.

This chapter will cover these points and help to narrow propeller choice for a given model to one or two diameters and pitches.

PROPELLER ACTION

A propeller generates thrust by forcing a column of air backward—called the "slipstream" as in Figure 1. In the slipstream, the air's velocity is increased above the aircraft's forward speed, and its pressure is reduced. In addition, a substantial part of this increase occurs ahead of the propeller. This slipstream swirls around the fuselage in the same direction as the propeller rotation.

A PAIR OF WINGS

A two-blade "prop" is actually a pair of small wings; each has an airfoil cross-section that is thick close to the hub for strength and rigidity,

and that tapers to the tips. These small airfoils have all the characteristics of a wing's airfoil. They have:

- A chord line;
- an angle of zero lift;
- a stalling angle;
- increasing profile and induced drags as their AoA increases;
- a pitching moment; and
- upwash ahead, and wake and downwash behind the blades.

Propeller blades differ from the wing's airfoil in that they operate at much higher speeds than the wing. A 12-inch-diameter propeller that advances 5 inches per revolution and turns at 10,000rpm has a tip speed of 360mph, while the model it propels flies at only 47mph.

A wing normally flies at the same speed across its span. A propeller, however, operates at different speeds: high at the tip and progressively slower from tip to root. At half its diameter, its speed is half that at the tip. Stresses on the propeller are

high, particularly at its center. These stresses result from a combination of centrifugal and thrust forces, plus the blade's airfoil pitching moment trying to twist them.

DIAMETER AND PITCH

Propellers are sized in both diameter and pitch in inches. Diameter is simply the length of the prop, tip to tip. It identifies the size of the imaginary cylinder in which the prop rotates and advances. Increasing the diameter increases the load
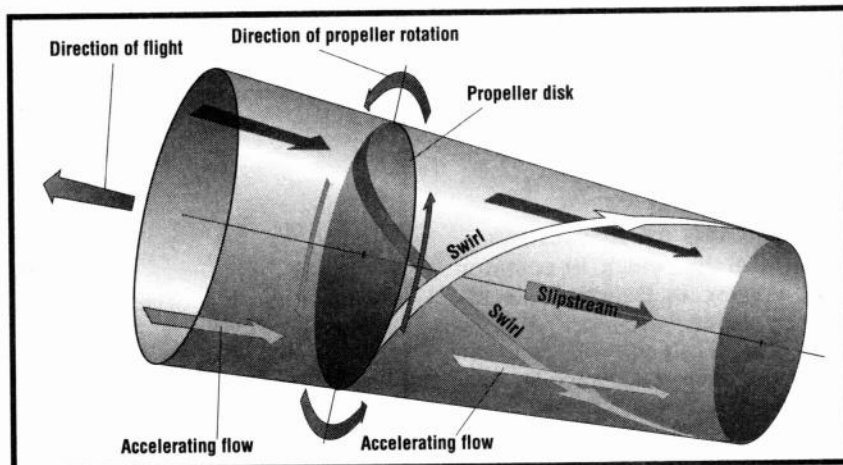

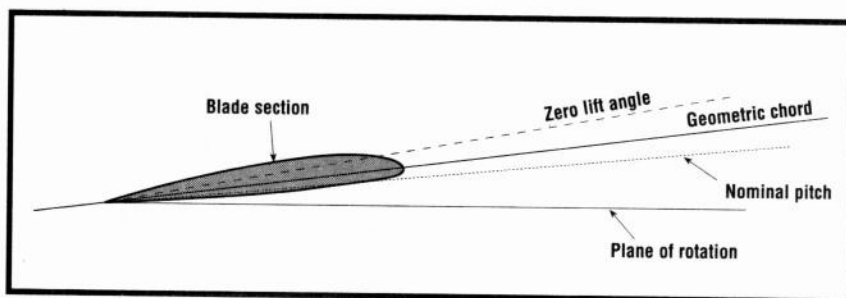**Figure 1.**
The propeller's action.

Figure 2.
Propeller pitches.

on the engine and reduces its rpm.

For each prop diameter, there are several different pitches available. For example, a 10-inch-diameter prop is typically offered in pitches from 6 inches to 10 inches. The higher the pitch, theoretically, the greater the advance per revolution, and the higher the engine load—again, reducing its rpm.

Thus, both diameter and pitch must be considered in propeller selection. For high-speed flight, reduced diameter and increased pitch apply; for slower flight, increased diameter and lower pitch prevails.

There are several variations for a given pitch dimension, as follows (see Figure 2).

■ The "nominal pitch" is measured across the flat back surface of the blade—usually measured at 75 percent of the diameter. This is what you buy!

■ The "geometric pitch" is measured across the airfoil's chord line.

■ The "true pitch" is the actual distance the prop advances per revolution. The difference between geometric and true pitch angles is the AoA at which the prop airfoil is truly operating and is called the propeller "slip."

PROPELLER AS AIRSCREW

A propeller has much in common with a screw. In fact, they are frequently called "airscrews." A screw being turned in a threaded hole will always advance its full pitch for each revolution. A propeller "screws" into air that is fluid. The advance per revolution is not fixed. A heavy model with high air drag and in a steep climbing attitude will offer high

resistance. Under these conditions, the propeller must operate at higher AoAs or slip, with increased profile and induced drags. This reduces the engine's rpm. It should be noted that, while pitch is a major factor in speed, a plane obviously can't fly faster in level flight than a speed that is close to that permitted by its geometric pitch multiplied by the rpm.

In a dive, with the engine at full rpm, the actual advance per revolution may increase to a point where the prop's airfoil is operating at a very low or a negative AoA. The profile and induced drag reduce substantially, the prop "unloads" and the engine over-revs—which does it no good! Experienced fliers throttle back in dives for this reason.

CONSTANT-PITCH PROPELLERS

Each point on a propeller blade—rotating and simultaneously advancing—describes a helix inside an imaginary cylinder. Consider one blade advancing one revolution;

imagine cutting the cylinder lengthwise down one side, from start to finish of that one revolution. Imagine opening and flattening it.

Figure 3 shows this flattened cylinder along with the geometric and actual pitches and blade cross-sections at 100 percent, 75 percent, 50 percent and 25 percent of the blade's length.

Note how the geometric angle of the blade varies from tip to root so that there is a constant AoA. Calling such a prop "constant pitch" is a bit of a misnomer; the blade is obviously twisted. "Constant angle of attack" is more accurate.

To calculate the propeller's speed at any point along its length is easy. Take the prop tip in Figure 3; in one revolution, it moves from A to B; AB is the hypotenuse of a right-angle triangle. Recalling high school geometry: "the square of the hypotenuse of a right triangle is equal to the sum of the square of the other two sides." In formula form and Figure 3:

$$AB = \sqrt{(AC^2 + BC^2)}$$

A 12-inch-diameter prop, advancing 5 inches per revolution, would have a hypotenuse of:

$$\sqrt{(12 \times 3.1416)^2 + 5^2}$$

or 38.02 inches.

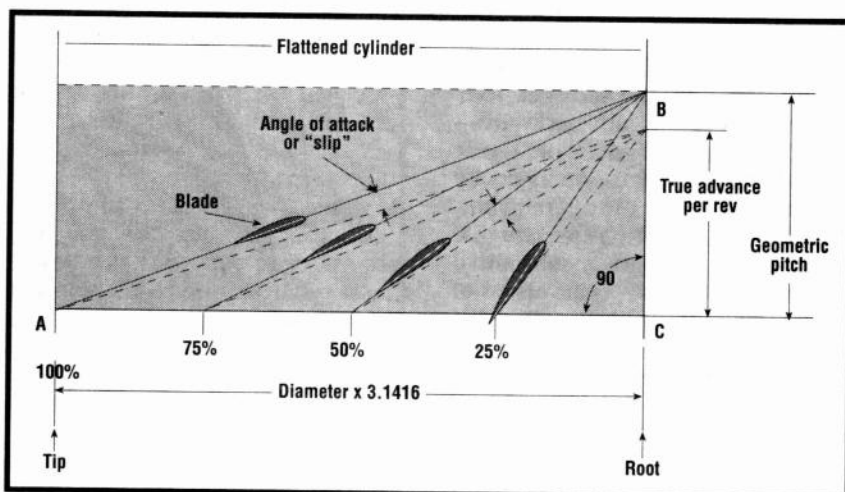Tip speed for this prop turning at 10,000rpm would be:

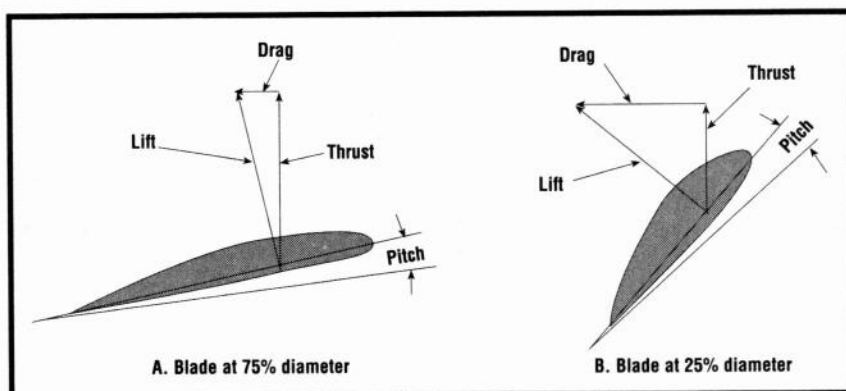*Figure 3.*
"Constant pitch" propeller.

Figure 4.
Lift, drag and thrust vectors at 75% and 25% diameters.

$$\frac{38.02 \text{ in.} \times 10{,}000\text{rpm} \times 60 \text{ min. /hr.}}{12 \text{ in./ft.} \times 5{,}280 \text{ ft./mi.}}$$

or 360.12mph.

At 50 percent of the blade length, the speed would be 50 percent of 360.12mph or 180.06mph. Those blades are lethal; take care!

Figure 4 shows blade cross-sections at 75 percent (A) and 25 percent (B) of the blade length from the hub. Both are operating at the same AoA. Note that at 25 percent, because of the blade angle, the lift is more inclined, the drag vector is increased and the thrust vector is reduced in comparison with the 75-percent point. This inner portion is less efficient, and from 25 percent to the prop center only worsens. A spinner of roughly 25 percent of the prop's diameter would cover this portion and would smooth out the airflow moving backward. For a 10-inch-diameter prop, a 2½-inch-diameter spinner does just that.

In Figure 4B, the higher blade angle, reduced thrust and increased drag reflect the effect of higher pitches for the prop as a whole. The increased drag reduces engine rpm; lower diameters are indicated. The reverse is also true; lower pitches with larger diameters.

THE AIRPLANE

The design of the model has a major bearing on the selection of its propeller diameter and pitch. The factors are:

■ **The weight and wing loading.** The heavier the model, for a given area, the higher its wing loading in ounces per square foot of wing area and the faster it must fly in level flight (or at higher AoA with higher drag).

Most models, in level flight, fly at C_L of 0.2 to 0.3. If you know the model's weight and calculate its wing area in square feet, its wing loading is easy to arrive at. Figure 5 provides a quick way to estimate the model's flight speed. Say the model's wing loading is 20 ounces per square foot; reading upward from 20 to C_L 0.2 and 0.3, level flight speeds are, on the left, 40 to 48mph. These speeds are minimums; something more is required for climbing and other maneuvers. Adding 25 percent gives speeds of 50 to 60mph and a mean speed of 55mph.

Now refer to Figure 15 (page 89): the rpm/pitch/speed nomograph. Place a straightedge at 55mph in the central, level-flight-speed column, and read off the static rpm and corresponding pitches that will provide 55mph. For example: a 7-inch pitch at 7,000rpm or an 8.5-inch pitch at 6,000rpm both provide 55mph.

The nomograph in Figure 15 is based on a 10-percent increase over the nominal pitch advance per rev and on a gain of 10 percent in engine revolutions as the prop "unloads" from a static position at high AoAs to the level flight speed at much lower AoAs. This graph will enable you to arrive at a reasonably close estimate of your model's top speed, based on the engine's static max rpm and its prop's nominal pitch. These results will never be 100 percent accurate, as the model's weight and drag will have an unavoidable impact, but they are close enough for all practical purposes.

■ **The model's aerodynamic drag.** A "clean" model such as the Swift will offer much less air resistance than one with an exposed engine, large flat windshield, large round or rectangular (in cross-section) wheels, unfaired landing-gear legs, dowels and rubber bands for wing-to-fuselage attachment, and other "built-in headwinds."

Parasite drag increases in proportion to the square of the speed. Doubling the speed results in a four-fold drag increase. High drag means increased "slip" (the prop will operate at higher AoAs) and rpm and flying speed will suffer adversely. Lower pitches and larger diameters are appropriate. While Figure 15 does not reflect the impact of high drag, it will put you "in the ball-park" as far as rpm and pitch are concerned.

■ **The weight-to-power ratio, or power loading.** A large engine powering a small, light model will obviously outperform a heavier, larger model powered by a smaller engine.

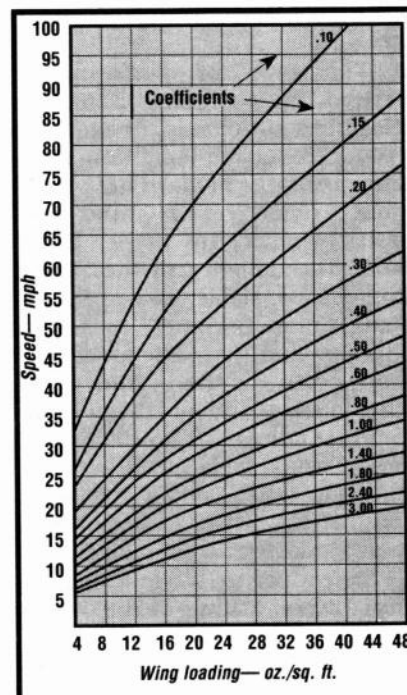With the large variety of both models and engines available, some

Figure 5.
Nomograph for quick determination of wing loading, lift and speed.

simple way of establishing the "weight-to-power ratio" is needed to permit ready comparisons. One way is to calculate what the weight in ounces would be if both engine and model were scaled up (or down) in proportion to 1 cubic inch of engine displacement (cid). For example, the Swift is powered by an O.S. Max .46 SF engine, and weighs, fueled, 92 ounces. Its weight-to-power ratio is 92/0.46, or 200 ounces per cid.

Another example is of a model weighing 300 ounces, powered by a 1.2ci engine. Its power loading is 300/1.2, or 250 ounces per cid. This comparison has obvious limitations. It assumes that power output of various sizes and makes of engines is proportional to their displacements—this assumption isn't too far off the mark. It's invalid for comparing 2-stroke with 4-stroke engines. Each class must be separately evaluated, e.g., 2-strokes should be compared with 2-strokes and 4 strokes with 4-strokes. Experience indicates that 2-stroke models with a 200-ounce per cid power loading that are well "propped" will have excellent performance. Higher power loadings, up to 300 ounces per cid, will result in diminished, but still acceptable, performance.

■ **The type of performance desired.** In designing a model, selecting a kit to build, or choosing a model to scratch-build from magazine plans, the modeler has performance objectives in mind that probably reflect his or her flying skills. The design goal may range from a slow, stable, easy-to-fly airplane (for a beginner) to a fast, high-powered, aerobatic model (for the expert). For the beginner, low wing loadings and a higher weight-to-power ratio of 275 to 300 ounces per cid would be in order.

At the other end of the scale, consider the Swift. Designed as a sport model with a wing loading of 22 ounces per square foot of wing area, a power loading of 200 ounces per cid and with the least drag that could be reasonably expected—short of retracts—it is fast, maneuverable and fun! It has flown with two propellers. The first, a 10x9, has a static rpm of 12,000. The sec-

TO CHOOSE A PROP

This procedure is recommended for selecting propellers for your model.

1. For a given coefficient of lift and wing loading, find the estimated airspeed as indicated in the nomograph (Figure 5). Increase the speed by 25 percent to allow for climbing and any appropriate aerobatic maneuvers, e.g., convert a 50mph estimate to 63mph.

2. Look at the rpm/speed/pitch nomograph (Figure 15), and pick out a pitch and rpm that will give you the airspeed you want.

3. Look at a published evaluation of the engine you are flying and see the reported rpm for various props tested on the engine. Also look for the rpm range where torque is maximized, if this information is provided. Pick a few props that provide rpm within the high-torque range and achieve the desired speed range.

4. Test these props at the flying field and stick with the one that provides the best performance.

ond, a 10x10 (a "square" prop) turns 11,000rpm static.

From Figure 15, level flight speeds are estimated to be 125 and 130mph—very close! This model's vertical performance is that of a "homesick angel"; it performs vertical 8s with ease and grace.

ENGINES

Today's model aircraft engines are fine examples of modern engine technology and precision machining. Most are "over square"—the bore diameter is larger than the stroke. This author prefers 2-stroke engines because they're simpler, more rugged, lighter, more powerful and less costly than the 4-stroke versions of the same displacement.

Engine-evaluation articles, such as those by David Gierke and Mike Billinton in *Model Airplane News*, and Clarence Lee in *R/C Modeler*, provide performance data on currently available engines and

insight into their design and construction. They provide tabulations of static rpm of an engine while it is powering various diameters and pitches of propellers. Table 1 shows Billinton's recording of rpm for the Fox Eagle 74 (*Model Airplane News*, October '91) and Table 2 shows that of Lee for this engine (*R/C Modeler*, March '91). In addition, Billinton provides performance curves of the 74 in Figure 7. Note that with silencer and standard .330 carb, the brake horse-power (b.hp) peaks at 15,000rpm, and the maximum torque is in the 7,000 to 11,000rpm range.

Data of this type—and the engine manufacturers' recommendations—provide very useful guides in selecting the diameter to match the pitch and rpm determined from Figures 5 and 15.

MATCH THE PROP

As previously noted, for a 20-ounces-per-square-foot wing loading, a 55mph speed is indicated, and a 6-inch pitch prop turning 8,000rpm is one possible selection. Look at Table 1 (Figure 6) for the Fox Eagle 74. A 15-inch diameter by 8-inch pitch prop would turn at around 8,000rpm. Figure 7 indicates that these rpm aren't too far off the peak of the torque curve for this engine. Another choice could be a 12x10 prop also turning in the 9,000rpm range. Like low gears on a car, the lower pitch of 6 inches would provide quicker acceleration and better climb, but lower top speed.

TOOLS

There are two items of equipment every serious modeler should possess. First is a photocell tachometer, either digital or analog, to measure the static rpm of your engine. It is useful to compare the performance of props of various diameters and pitches with the published data as described above. These tachometers may be used safely from behind the prop, and they aren't expensive. The second tool is a propeller balancer, the type with two sets of overlapping, free-turning disks. Balance every prop—you'll be surprised how many require balancing—to avoid vibration. On reinforced plastic props, a coat of silver

TABLE 1

Prop diameter, pitch and make ..RPM
18x8 Top Flite 5,190
15x8 Graupner 7,700
15x8 APC...........................8,030
16x5 Zinger 8,078
14x8 APC...........................9,180
13x6 MK 11,040
12x6 APC 12,814
11x5 Top Flite 13,960

Mike Billinton's evaluation of the Fox Eagle 74 with various names, diameters and pitches of propellers.

TABLE 2

Prop diameter and pitch ....RPM
11x8 12,200
11x10 10,900
12x6 12,100
12x8 11,000
12x10 9,000
13x6 12,450
14x6 10,150

Clarence Lee's evaluation of the Fox Eagle 74 with various diameters and pitches of Zinger props.
Figure 6.

paint (after a gentle surface roughing with fine sandpaper for better paint adherence) will aid the photocell to "see" the prop. Any imbalance is easily corrected by adding paint to the lighter blade.

All this will narrow the choice to two or three props. However, there is just no substitute for actual flight tests in your final selection to obtain the performance sought and the optimum output of prop and engine.

PROPELLER MATERIALS

Props are available in wood, nylon and reinforced plastics. This author favors the reinforced plastic props because of their ruggedness and efficiency, even though they weigh roughly twice the weight of their wooden equivalents. Avoid unreinforced nylon props; they lack enough rigidity for use during high power.

PROPELLER EFFECTS

■ **Slipstream.** The slipstream (see Figure 1) moves as a helix rotating

around the airplane in the same direction as the propeller's rotation, but at higher than flight speed. It strikes body, wing and tail surfaces at angles and increases the drag of any obstacle in its path. Its most unfavorable impact is on the vertical tail surface—it causes yawing that calls for rudder-trim correction.

The increase in the velocity of the oncoming relative wind (i.e., ahead of the prop) reduces the prop's effective pitch, as does one blade's downwash on the next. Such downwash further reduces the prop's efficiency. The situation is made worse with three or more blades. For model airplanes, such multi-blade props aren't recommended, except for scale models of aircraft so equipped.

In full-scale aircraft, multi-blade props are used to absorb the high power of modern piston and turbo-prop engines. They also reduce the propeller's diameter so as to avoid compressibility effects from tip speeds close to the speed of sound. The loss of efficiency in this reduction must be accepted.

■ **Asymmetric blade effect.** When the plane of the propeller is inclined to the direction of flight as in Figure 8, the advancing blade operates at a higher AoA than the retreating blade. Thrust on the advancing side is higher than on the retreating side. This causes a pitching or yawing couple.

■ **Pitching moment.** When the thrust line is tilted as in Figure 9, a vector is introduced that causes a pitching moment. It may combine with the asymmetric blade effect.

■ **Torque.** The resistance to rotation caused by the prop's drag tries to rotate the whole airplane in the opposite direction. This is particularly true in a steep climbing attitude at low forward speed and maximum rpm where the prop is operating at high AoAs, such as just after liftoff. A touch of opposite aileron input may be needed to offset the torque.

■ **Gyroscopic precession.** Like a gyroscope, a rotating propeller resists any effort to change the

direction of its axis. The heavier the propeller and the higher the rpm, the greater this resistance. If a force is applied to tilt the plane of the prop's rotation, it is *"precessed" 90 degrees onward, in the direction of the prop's rotation.*

This effect shows up markedly on tail-dragger takeoffs if the tail is lifted too soon and too high. Precession causes a yaw to the left (for props rotating clockwise, viewed from behind) that could result in a ground loop unless corrected by rudder action.

The author's flying-boat design, Seagull III, was initially flown with a Graupner 11x8 prop that was mounted in a pusher configuration with the propeller's plane of rotation directly over the CG (the thrust line was 6 inches above that CG). Coming out of a left-hand turn, the model would enter an uncommanded, gentle right-hand turn, nosing down slightly. It was easily corrected, but annoying. Replacing the Graupner (an excellent prop) with a Zinger wooden equivalent of half the Graupner's weight eliminated this peculiarity.

NOISE

Many clubs are experiencing problems because of noise that originates from two sources: the engine itself and the propeller. Engine mufflers and tuned pipes now available go a long way to reduce engine noise to acceptable levels.
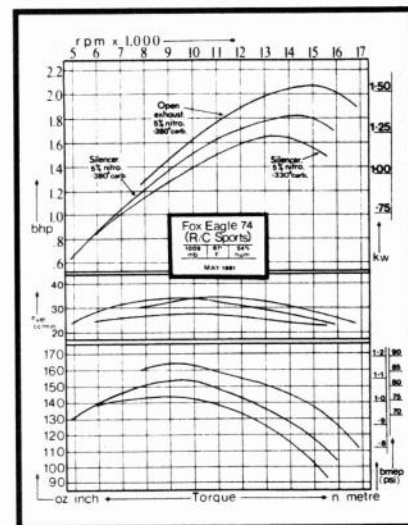

Figure 7.
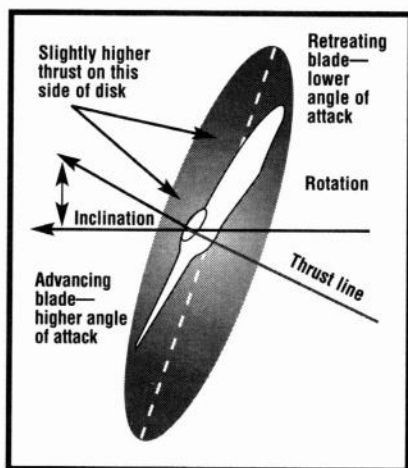*Performance curves for the Fox Eagle 74.*
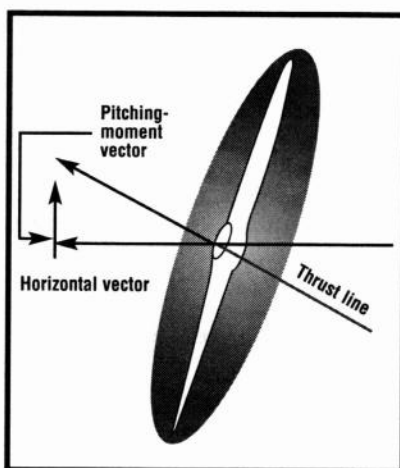
Figure 8.
Asymmetric blade effect.

Figure 9.
Propeller pitching moment.

Regarding prop noise, there's a trend to long-stroke engines that develop their highest torque at lower rpm so that, for example, they can swing props with increased pitches. Higher pitches and lower diameters reduce tip speeds and prop noise. Propellers with pitches equal to their diameter or greater (over square), such as 11x11s, 11x12s, 11x13s and 11x14s, are now widely available.

LEVEL FLIGHT SPEEDS
For both full-scale and model airplanes, good design practice requires that the angle of incidence at which the wing is set (on the drawing board) result in the lowest fuselage and horizontal tail drag at the aircraft's selected cruising speed.

At lower speeds, the aircraft must nose-up, through elevator trim, to achieve the AoA that provides adequate lift. At higher speeds, the reverse takes place; down-elevator trim reduces the AoA.

To determine the wing's angle of incidence, you need the wing's airfoil and its lift/drag curves; the aircraft's gross weight in ounces; the wing's area in square inches; and last, but not least, the selected level-flight speed in mph.

It is assumed that the lowest drag will occur when the model flies with its fuselage centerline horizontal. The wing's angle of incidence, relative to that centerline, will then be the same as the calculated AoA.

Figures 10A and 10B show the effect of too much incidence or too little. In both cases, fuselage and horizontal tail drag is higher.

The problem is to estimate the model's level-flight cruising speed. Some chaps like to fly around the "pea patch" at maximum rpm and top speed; others, such as yours truly, are more conservative and enjoy flying at something less than top speed—say, 75 percent of the model's highest speed. Either way, evaluation of the aircraft's top speed is required.

Some years ago, a nomograph was developed for quickly determining a model's speed based on its engine's maximum static rpm and the nominal pitch of the propeller being rot-ated at those rpm. The nomograph was based on two assumptions:

■ In top-speed flight, there would be a gain of 10 percent in rpm, since the prop is operating at a lower angle of attack, with less drag, than it would if the model was stationary.

■ A loss of 15 percent in advance per revolution of the prop compared with the prop's nominal pitch advance. This was incorrectly based on the oft-repeated statement that a prop/engine combination developed only 85 percent of the engine's output in terms of thrust.

DAVID GIERKE'S INITIATIVES
David Gierke's "Real Performance Measurement" (RPM) reports in *Model Airplane News* on engine and propeller performance are, in this writer's opinion, outstanding—a real breakthrough and a major contribution to model airplane design.

For each engine under study, he provides not only horsepower and torque curves and details of its construction and handling, but also static and level-flight rpm and the model's actual airspeed at those rpm. He uses a variety of prop makes, diameters and pitches that are suitable for the engine being evaluated.

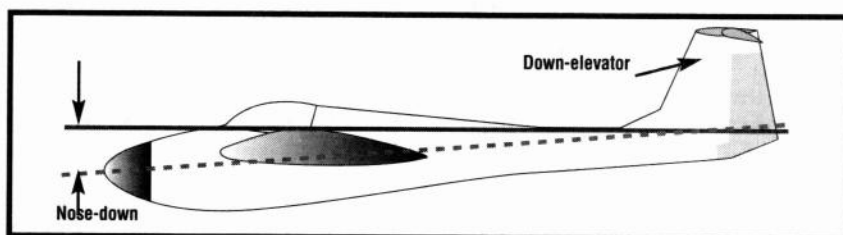■ Knowing static and flight rpm allows you to evaluate the gain in revolutions in flight.

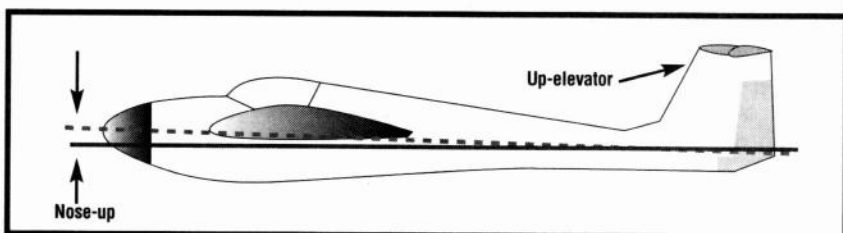Figure 10A.
Too great an angle of incidence.

Figure 10B.
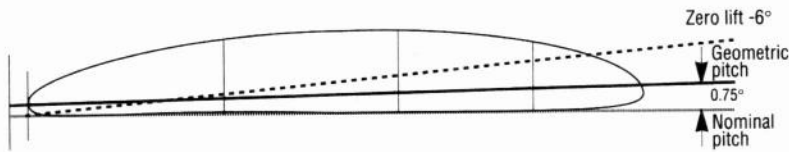Too little an angle of incidence.

Propeller airfoil sections
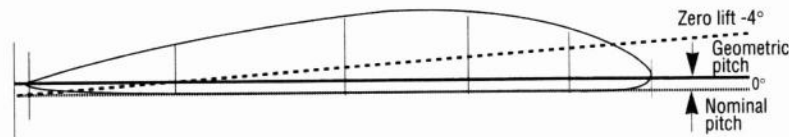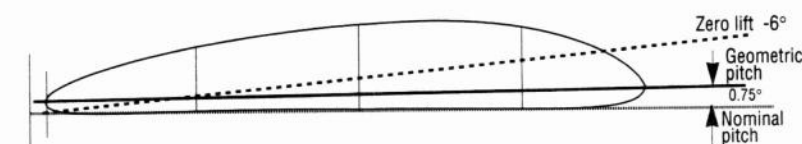

Figure 11.
Graupner prop section.
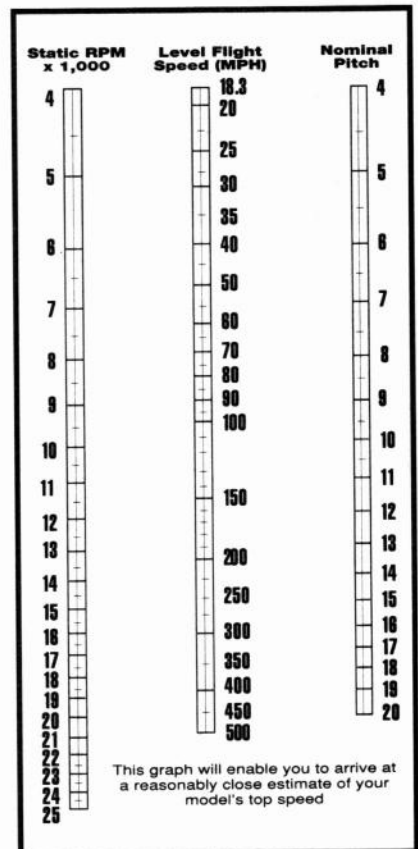

Figure 12.
APC prop section.

Figure 15.
This nomograph will enable you to arrive at a reasonably close estimate of your model's top speed. Align a straightedge from rpm (left) to prop nominal pitch (right). The speed in mph is read off the center scale.

■ Knowing in-flight speeds and rpm allows you to calculate the actual advance per revolution and compare it with the prop's "nominal" pitch advance.

This calculation is:

Advance per rev =
$$\frac{\text{Speed x 5,280 (ft./mi.) x 12 (in./ft.)}}{\text{rpm x 60 (min./hr.)}}$$

Analysis of David's figures brought two facts to light:

■ The assumption of a 10-percent gain in rpm from static to level flight was not too far off.

■ The big surprise was that the advance per revolution exceeded the prop's nominal pitch by anywhere from 7 to 18 percent.

Figure 12 is a prop blade section. For the actual advance per rev to exceed the nominal pitch advance, the blade's actual AoA must be somewhere between the "nominal pitch" and "zero-lift" angles. The nominal pitch is measured, with a pitch gauge, on the blade's rear surface, at a point 75 percent of the blade's length, measured from the prop's center. The blade's airfoil, the leading-edge radius and its position relative to the nominal pitch all have a bearing (see Figures 11, 12, 13 and 14). ▲

Flight speeds
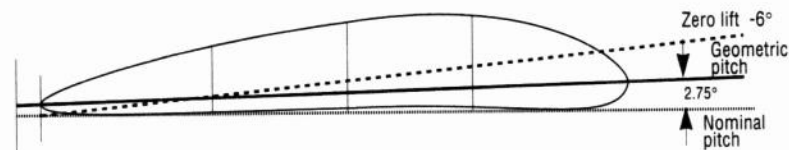
Figure 13.
Master Airscrew section.

Figure 14.
Wooden "power" prop section.
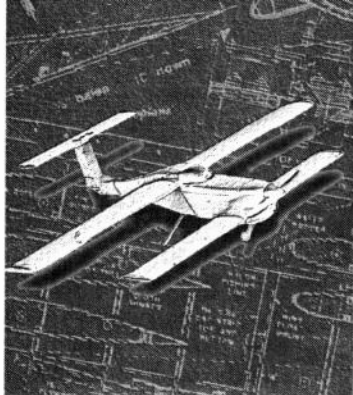
Chapter 19

Design for Aerobatics

In the design of an aerobatic model airplane, the first consideration must be for the heavy loads—both aerodynamic and structural—imposed by centrifugal

Model 1—the Swift.

force in high-speed, sharp, turning maneuvers. These loads are in addition to the model's own weight.

A pattern ship flying at 100mph in a 120-foot-diameter (60-foot radius) turn will sustain loads of more than 12 times its gross weight. If the combination of wing area and the airfoil's C_L max is incapable of supporting this load, a high-speed stall will result. A panicked pull-up from a steep dive, at low altitude, that results in such a stall could be very damaging. Similarly, the model's structure must not fail under such heavy loads (see Chapter 13, "Stressed Skin Design").

It's true that at the higher AoAs needed to support these loads, the

model's drag will increase enormously; this slows the model and reduces the load. The highest load, therefore, occurs at the start of the maneuver—before drag slows the model appreciably. The problem lies in selecting the wing area and airfoil section that will support these heavy loads. To better understand this, five model aircraft with wing areas of from 400 to 800 square inches were analyzed.

The basis for this analysis is model 3, which reflects the specifications of the author's Swift. This model has a wing area of 600 square inches and grosses 92 ounces with a full tank (a glow-powered airplane with an empty tank cannot fly!).

All five have the same 0.46ci engine, R/C equipment and landing gear. Analysis of the Swift's weight discloses that the power and control units, plus landing gear accounted for 48.5 ounces. It was estimated that for each 100 square inches of wing area added to or subtracted from the 600 square inches, there would be a weight change of 5 ounces; a 700-square-inch-area model would gross 97 ounces, and a 500-square-inch version would weigh 87 ounces.

The Swift's power loading of 200 ounces per cubic inch of engine displacement permitted sustained ver-

tical climbs and vertical 8's with little discernible speed change.

All five wings used for this comparison *have AR 6* and taper ratios of 0.6, i.e., tip chord = 0.6 x root chord, and were unswept (see "Wing Area Analysis" chart).

AIRFOIL SELECTION
Symmetrical sections perform equally well inverted and upright, have zero pitching moments and are ideal for aerobatic models. The airfoil used in this study was NACA 64_1-012—an early laminar-flow airfoil. NACA Technical Note 1945 provides data on this airfoil and NACA 0012 at Rns down to 700,000 (0.7×10^6). A 10-inch-chord wing flying at 100mph at sea level is operating at an Rn of 780,000.

The disadvantage of symmetrical airfoils is their low maximum lift capability compared with cambered airfoils. This has two effects:

■ At high-G loads, additional wing area is needed.

■ Landing speeds will be higher, unless slotted flaps are used.

At Rn 700,000, NACA's 64_1-012 airfoil has a C_L max of 0.9 and a minimum C_D of 0.007.

NACA 0012 has C_L max of 1.05 and minimum C_D of 0.0065 at Rn
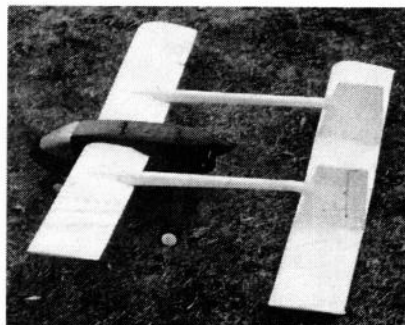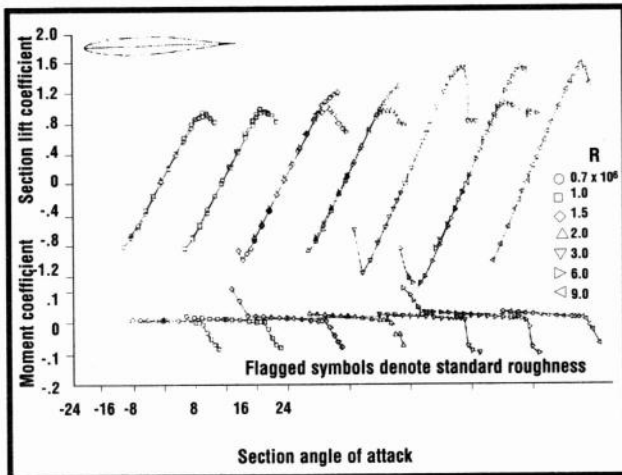

Model 2—the Wasp tandem wing.
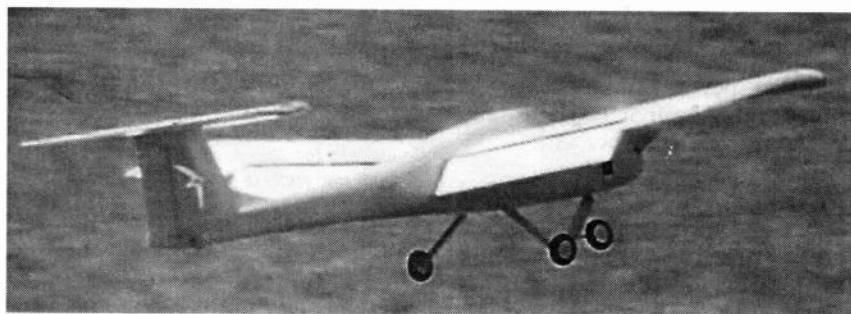
Figure 1.
Section lift and pitching-moment characteristics of the plain NACA 64_1-012 airfoil section, 24-inch chord.
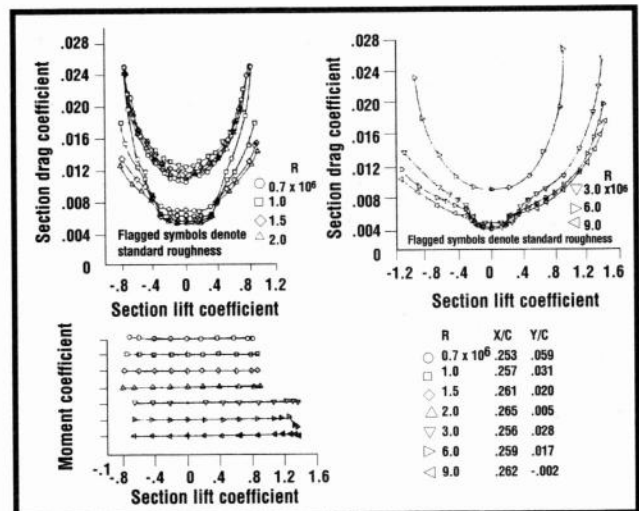

Figure 2.
Section drag characteristics and section pitching-moment characteristics about the aerodynamic center of the plain NACA 64_1-012 airfoil section.
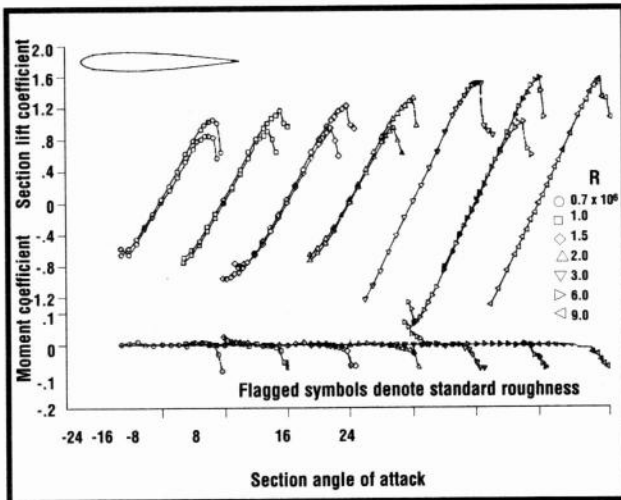

Figure 3.
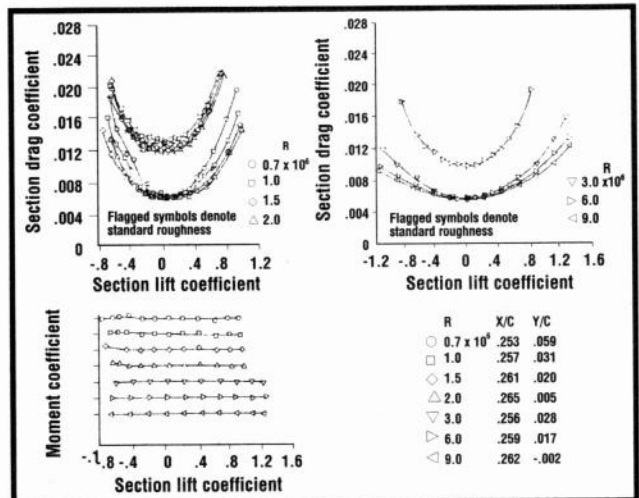*Section lift and pitching-moment characteristics of the plain NACA 0012 airfoil section, 24-inch chord.*

Figure 4.
Section drag characteristics and section pitching-moment characteristics about the aerodynamic center of the plain NACA 0012 airfoil section.

700,000 and would have been a better choice considering the Rns of these models. However, 64_1-012 was used in the calculations (see Figures 1, 2, 3 and 4).

Model 3—the Canada Goose canard.

DRAG

Other important considerations are wing drag, profile drag and particularly induced drag. A model with high wing drag in both level flight and under high G-force will not perform as well as one with lower drag under both. The chart shows some startling comparisons of level-flight drag to high-G-force drag.
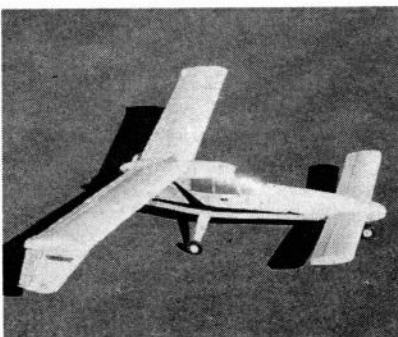
This study considers only total wing drag; it does not include the drag contributions of fuselage, tail surfaces and landing gear. Although the tail feathers would vary in proportion to each model's wing area, the fuselages would all have the same cross-sectional area and

would change only slightly in length; the difference in their contributions to each model's total drag would be minimal.

COMMENTS

■ **Model 1**—400-square-inch area. The C_L of 0.874 is dangerously close to 64_1-012's C_L max of 0.9. Since this model's level-flight drag is the lowest, it could exceed the 100mph speed, despite its high-G wing drag of 77 ounces, and it could stall at high speed. Its small size would adversely affect its visibility, and its landing speed is high.

■ **Model 2**—500-square-inch area. Much the same as for model 1, with

Wing Area Analysis

Model no.	Wing area (sq. in.)	Gross weight (oz.)	Wing load at 12.12 G's at 100mph (in oz.)	Wing drag at 12.12 G's at 100mph (in oz.)	Wing drag in level flight at 100mph (in oz.)	Wing loading (oz./sq. ft.)	Power loading (oz./cid)	Lift coefficient at 12.12 G's at 100mph	Landing speed (stall speed mph + 20%)
1	400	82	994	77	6.6	29.5	178	0.874	35
2	500	87	1,054	69	8	25	189	0.742	33
3	600	92	1,115	67	9.7	22	200	0.654	29
4	700	97	1,175	67	11.2	20	210	0.590	27
5	800	102	1,236	67	16	18.4	222	0.544	26

Model 5—the Wild Goose three-surface airplane.

the exception that the lower C_L at high G's of 0.742 compared with the C_L max of 0.9 provides an improved safety margin against high-speed stalls. Landing speed is high.

■ **Model 3**—600-square-inch area, which is the optimum in this author's opinion. At 0.654, its high-G lift coefficient provides a good safety margin. Its level-flight wing drag of 9.7 ounces is good, and its high-G wing drag is reasonable. Landing speed of 29mph is acceptable. Its power loading of 200 ounces per cubic inch displacement proved satisfactory on the Swift, and it is large enough to be readily visible.

■ **Models 4 and 5**—700 and 800-square-inch areas, respectively. Both have the same high-G wing drag; but level-flight wing drag increases with the added wing area. Combined with the models' greater weights, this would adversely affect maneuverability. The greater wing area results in lower landing speeds and better visibility.

FORMULAS

In developing this comparison, formulas published in previous articles were used and are repeated below

with examples for any fellow designer to follow.

■ **Centrifugal force**
$$G's = 1 + \frac{(1.466 \times speed—mph)^2}{Turn\ radius\ (feet) \times 32.2}$$

At 100mph and turn radius of 60 feet,
$$1 + \frac{(1.466 \times 100)^2}{60 \times 32.2} = 12.12\ G's$$

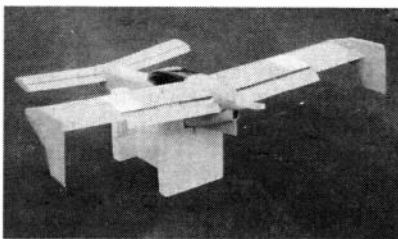■ **Lift coefficient needed**
$$C_L = \frac{Gross\ weight\ (oz.) \times 3519 \times G^*}{Speed^2 \times Wing\ area\ (sq.\ in.) \times K}$$
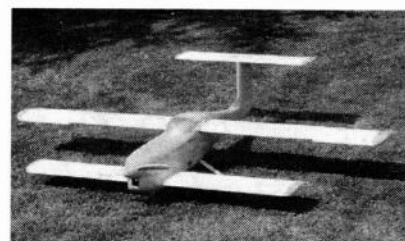
At sea level, K is 1.00; at 5,000 feet, 0.8616; and at 100,000 feet, 0.7384.
* If greater than 1G,

$$C_L = \frac{92 \times 3,519 \times 12.12}{100^2 \times 600 \times 1} = 0.654$$

Model 4—the Swan canard.

■ **Wing-drag coefficient**
The profile C_D of airfoil 64$_1$-012 at a C_L of 0.654 is 0.0155 (see Figure 2). The total of both profile and induced drags is:

$$Profile\ C_D + \frac{0.318 \times lift\ C_L^2 \times (1 + \delta^*)}{Aspect\ ratio}$$

*δ (delta) is the wing planform correction factor. For a wing of taper ratio 0.6, it is 0.5.

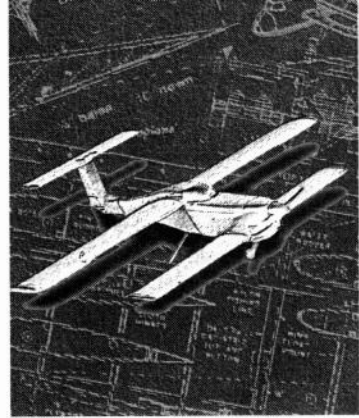$$0.0155 + \frac{(0.318 \times 0.654^2 \times 1.05)}{6} = 0.393$$

■ **Wing drag (ounces)**
$$Drag\ (oz.) = \frac{Total\ wing\ C_D \times speed^2 \times wing\ area}{3,519}$$

At 12 G's,
$$\frac{0.0393 \times 100^2 \times 600}{3519} = 67\ oz.$$

Plug in the numbers, and the formulas may be solved using simple arithmetic. Happy designing! ▲

Chapter 20

....

High-Lift Devices and Drag Reduction

High-lift devices (HLDs) on a model specifically designed to take advantage of the substantial lift and drag increase they provide, coupled with good drag reduction techniques, will result in smaller lighter, more nimble airplanes, with a greater range of speeds, from stall to top speed. Their appearance will be sleek—very similar to today's full-scale planes—yet they will be sturdy and capable of sustaining high-G loads of centrifugal force in their maneuvers.

The homebuilt movement, in cooperation with the Experimental Aircraft Association (EAA), has developed many superb full-scale, single-engine airplanes of composite construction. They have excellent performance on relatively low horsepower. These are the "Lancairs," "Glassairs," "Swift Lightning" and "Pulsars," to name a few. Their outstanding performance is due to good design and careful drag reduction. All have flaps to permit acceptable landing speeds. In contrast, most

The Crow in level flight.

current models are reminiscent of the high-drag aircraft of the '30s.

Very few modelers take advantage of HLDs and drag reduction. Flaps are limited largely to scale models of aircraft so equipped. Hopefully, this article will persuade modelers to incorporate flaps and drag reduction in new and innovative designs; the benefits justify the effort.

STALL AND LANDING SPEED

Landing speeds have not been much discussed in the model airplane press, but are a major consideration in full-scale design. Landing speeds are a function of the model's stalling speed, which in turn, depends on weight, wing area and the airfoil's maximum lift capacity. Weight and wing area are combined in the form of "wing loading" in ounces per square foot of wing area.

At a wing loading of 16 ounces per square foot and wing max C_L of 1.00, the stall speed is 20mph. At a wing load-
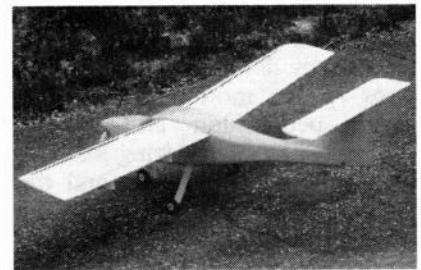
The Crow at rest. Note the wing's high-lift devices (HLDs).

ing of 40 ounces per square foot, stall speed increases to 33mph. If the wing max C_L could be increased with the HLDs to 2.40, the stall speed would still be 20mph at 40 ounces per square foot. (See Figure 5 of Chapter 18, "Propeller Selection and Estimating Flight Speeds.")

U.S. Federal Air Regulations (FARs) specify a stall speed of not more than 60 knots (or 69mph) for aircraft weighing less than 12,500 pounds of gross takeoff weight. Sixty-nine miles per hour is as fast as some models can fly at top speed! Most light, single-engine, full-scale aircraft stall, flaps extended 40 degrees, power-off and at gross weight at about 50mph. This is still too high for model aircraft. A "scale" speed is needed!

In "scale realism" (*Model Airplane News,* September 1993 issue), Kent Walters' suggestion that scale speeds be calculated using "the square root of the scale factor" is explained. This is a very sensible suggestion. Most

SPECIFICATIONS	MODEL A	MODEL B
Wing area (sq. in.)	750	500
Fueled weight (oz.)	96	88
Wing planform	Constant chord	Constant chord
Aspect ratio	6	6
Span (in.)	67	54.75
Chord (in.)	11.2	9.13
Wing loading (oz./sq. ft.)	18.4	25.3
Wing airfoil	E 197	E197
Tail airfoil	Flat	E168
Airfoil C_L max	1.17	1.8 (flaps at 40°)
Power (cid)	0.46	0.46
Power loadings (oz./cid)	208.7	191.3
Propeller	11x6	10x9
Rpm	11,000	11,000
Est. max speed (mph)	75	100
Est. stall speed (mph)	19.5	18
Servos	4	5

.40- to .50-powered models will be about ⅙ or ⅟₇ of the size of their big brothers. The square roots of these scale values are 0.408 and 0.378, respectively. Multiply 50mph by these numbers: 50 x 0.408 = 20mph and 50 x 0.378 = 18.9mph. A model's stall speed of 20mph seems reasonable. FAR no. 23 stipulates that approach speeds should be 1.3 times the stall speed, or 26mph. Twenty-five to 30mph are sensible speeds—fast enough for good control response, but slow enough for good pilot response.

In the absence of an airspeed indicator, it is not possible to judge a model's exact speed. If the glide is too flat and slow, most models will alert their pilots by gently stalling and nosing down (a signal to apply a bit of nose-down elevator trim).

A model with slotted flaps flying on a windy day lands into the wind *flaps up* for more airspeed with better penetration and control response. The higher wing loadings are less affected by gusts, and the touchdown speed is reduced by the wind's velocity. An unflapped model, with a lower wing loading, is easily disturbed by gusts, making landings more difficult.

MAXIMUM LIFT COEFFICIENT

To determine the C_L max for an unflapped wing, a simple and rea-

Flaps down, the Crow is descending.

sonably accurate method is to use the C_L max of the wing's airfoil. For E197, this is 1.17. For a wing with partial-span slotted flaps of 30 percent of the wing's chord in width, the flapped portion will produce an additional C_L of 1.05 at 40 degrees deflection (see Figure 10 of Chapter 3, "Understanding Aerodynamic Formulas"). Using E197 again, the flapped portion provides 1.17 + 1.05, or a C_L max of 2.22. The unflapped area has a C_L max of 1.17. To obtain the average C_L max, proceed as follows:

Unflapped area (sq. in.) x 1.17 = x
Flapped area (sq. in.) x 2.22 = y
Total area = x + y

To find the average C_L max, divide (x + y) by the total area. That portion of the wing in or on the fuselage is considered as unflapped wing area.

Obviously, a tapered wing of equal area and aspect ratio, compared with a constant-chord wing and the same length of slotted flap, would have a higher C_L max, since a greater portion is "flapped" (see Figure 1). To determine the stall speed, flaps down, refer to Figure 3 of Chapter 1, "Airfoil Selection"; knowing the model's loading and C_L max, the stall speed is read off the vertical left-hand scale for sea-level conditions; otherwise, use this formula (WA = wing area; DF = density factor):

Stall speed mph =

$$\sqrt{\frac{\text{weight (oz.) x 3519}}{C_L \text{ max x WA (sq. in.) x DF}}}$$

The density factor at sea level is 1.00; at 5,000 feet of altitude, it's 0.8616; and at 10,000 feet, it's 0.7384. This is one variation of the lift formula; involved are four factors: weight, wing area, speed and lift coefficient. Knowing three, the fourth is easily calculated as follows:

Lift (oz.) =

$$\frac{C_L \text{ x speed}^2 \text{ (mph) x WA (sq. in.) x DF}}{3,519}$$

Wing area (sq. in.) =

$$\frac{\text{Lift (oz.) x 3,519}}{C_L \text{ x speed}^2 \text{ (mph) x DF}}$$

Lift coefficient =

$$\frac{\text{Lift (oz.) x 3,519}}{\text{Speed}^2 \text{ (mph) x WA (sq. in.) x DF}}$$

DESIGN COMPARISONS

To illustrate the advantages of HLDs and drag reduction, the specifications of two models (A and B) are outlined—both designed for stall speeds close to 20mph. Both are powered by .46ci engines and have the same control unit, but model B has an extra (fifth) servo for flap actuation.

Model A is typical of many models seen at any flying field: exposed engine; small spinner (or none); bare music-wire landing gear leg; big fat wheels, flat windshield; square cross-section fuselage; dowels; and rubber-band wing hold-downs; flat
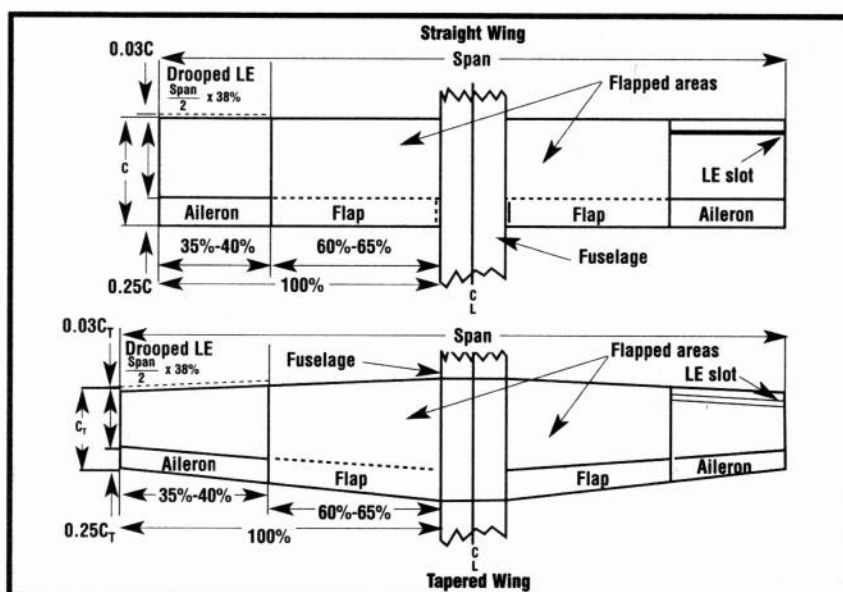

Figure 1.
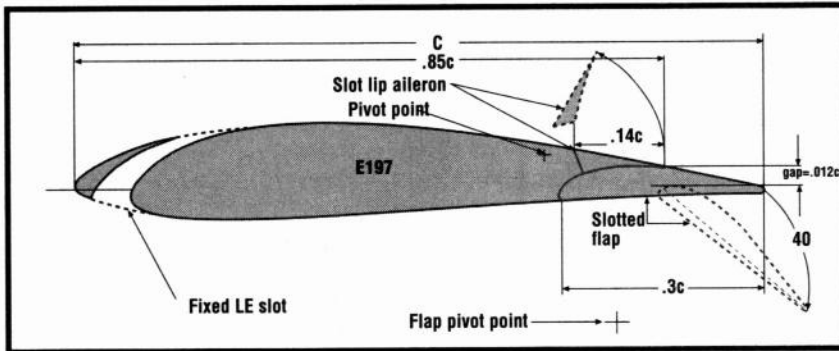*Desirable flap proportions for straight-wing and tapered-wing designs.*

Figure 2.
The Crow's wing airfoil section.

balsa tail surfaces; exposed control horns; lots of "built-in headwinds" (beneficial for steepening the model's glide and making landings easy). It has no flaps. The wing is D-spar construction, plastic-film-covered; the fuselage is lite-ply; and the tail surfaces are ¼-inch balsa sheet.

Model B has a ducted cowl enclosing the engine; a large spinner; landing-gear leg fairings; small streamlined wheels; concealed wing hold-downs; balsa-sheeted, stressed-skin structure with a film overlay; streamlined windshield; and mini-
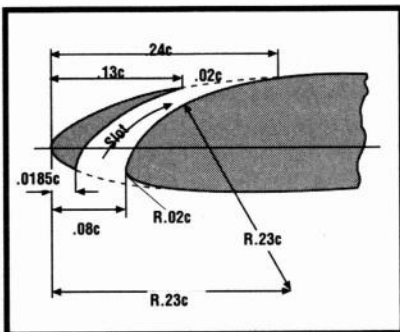
Figure 3.
Geometry of the fixed leading-edge slot.

mum exposure of control horns. It has slotted flaps, 30 percent of the wing chord in width and 60 percent of the semi-span in length.

Because of its sleek, low-drag design, similar to the Swift's, it is capable of high speeds. Mass balancing of ailerons, elevator and rudder is incorporated to avoid flutter that could be very damaging.

WEIGHT ANALYSIS

Look at the chart on page 93. The power and control units and landing gear of model A weigh 45

ounces, leaving 51 ounces for the structure of fuselage, wing and tail surfaces. Model B's wing area is two-thirds that of model A; it is reasonable to estimate that model B's *structural* weight would be two-thirds of model A's, or a weight reduction of 17 ounces.

Model B's weight would, however, be increased by the ducted cowl, large spinner, landing-gear leg fairings, full balsa stressed skins, flaps plus their servos and linkage, mass balancing of control surfaces and a 700mAh battery replacing the usual onboard unit of 500mAh. This is estimated to add 9 ounces, leaving 8 ounces, reducing model B's weight to 88 ounces. The Crow at 500 square inches of wing area, grossed 87.5 ounces, confirming model B's estimated weight.

As for model A, the Osprey had a wing area of 768 square inches and weighed 113 ounces. It had slotted flaps, six servos, a ducted cowl and heavy landing gear weighing 14.5 ounces The fuselage was heavily reinforced for use with twin floats. The fuselage, wing and tail surfaces were not fully balsa-sheet-covered. By comparison, model A's fueled weight of 96 ounces for 750 square inches of wing area is conservative.

■ **Drag comparison.** At 70mph, model B's wing would have 4 ounces less profile and induced drag than model A's wing; but that's not all! The engine cowl, spinner, shorter rounded fuselage, smaller tail surfaces, landing-gear leg fairings and small streamlined wheels, overall smoother surfaces and absence of dowels and rubber bands holding the wing are conservatively estimated to reduce drag by a

further 8 ounces (at 70mph) for a total drag reduction of 12 ounces, permitting a higher top speed for model B. This is confirmed by experience with other previous designs.

■ **Takeoffs.** Assuming rotation at liftoff to 8 degrees AoA, unflapped model A would become airborne at 24mph. Model B, flaps extended to 20 degrees and similarly rotated to 8 degrees, would be airborne at 20mph with a shorter takeoff and steeper climb, flaps still extended. With its lower power-to-weight ratio (power loading) of 191.3 oz./cid, model B's lower drag would permit sustained vertical climb.

FLYING FLAPPED MODELS

Windy-day landings, flaps up, have been discussed. On a quiet day, wind-wise, the model may be slowed, flaps fully deployed, and nosed down as steeply as 45 degrees to the horizontal. The flap drag will limit the model's terminal velocity. There is no possibility of a stall and, at a reasonable height above the ground, the model is flared for a short-field landing. Landing flaps-up on such a day will be tricky; the glide is fast and flat, and overshooting the landing area is a real possibility. Maneuvers under power, flaps extended, can be almost incredibly tight, and the flaps themselves are sturdy enough to permit this treatment.
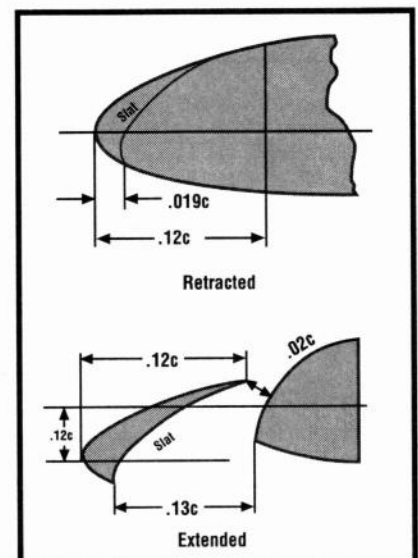

Figure 4.
Geometry of the retractable LE slat.

One advantage of the "30 percent of wing chord flaps with extended lip" is that there is very little pitch change when lowering the flaps. The Swift continued on its merry way on lowering full flaps, but it flew appreciably more slowly.

■ **Centrifugal force.** One concern with higher wing loadings, such as for model B, is that in a tight turn or sharp pull-up, centrifugal force plus the model's weight could exceed the wing's maximum lifting capacity. This could result in a dangerous, high-speed stall, particularly when pulling out of a steep dive at a low altitude. Assuming a turning radius of 60 feet (120-foot diameter), the following tabulates the G-forces involved compared with model B's maximum lift capacity, also in G, at various speeds.

Speed (mph)	Wt. + cent.* lift (G)	Wing max. lift (G)
60	5.00	6.80
70	6.45	9.25
80	8.11	12.00
90	10.00	15.30
100	12.12	18.90

centrifugal

For model B, lift exceeds load at all speeds. Note the loads the model's structure must sustain at higher speeds. In a tight turn at 90mph, the load is 880 ounces, or a surprising 55 pounds.

■ **Wing trailing-edge HLDs.** Figure 1 of Chapter 14, "Design for Flaps" and Figure 12 of Chapter 5, "Wing Design," describe and show the additional lift provided by five types of flap: plain, split, slotted, slotted with extended lips and Fowler.

The most practical type, giving the optimum additional lift with lowest added drag, is the 30 percent of chord slotted flap with extended lip. These are easily operated by one standard servo; they're rugged and very effective. Because of their low drag at 20 degrees extension, they may be used for takeoff advantage. Figure 2 illustrates the flap design for the Crow's wing. The only disadvantage is the longer streamlined arms from flap to pivot point needed to provide the backward movement from 0.7 percent of chord to 0.85 or 0.9 percent of chord.

Though the Fowler flap provides greater lift, its backward and downward motion demands complex pivoting arms or other mechanisms and powerful servos.

■ **Wing LE high-lift devices: LE slots.** Figure 3 illustrates fixed LE slots; Figure 4, retractable LE slats. Figure 5 shows the benefit of fixed LE slots: an increase in C_L max of 0.4
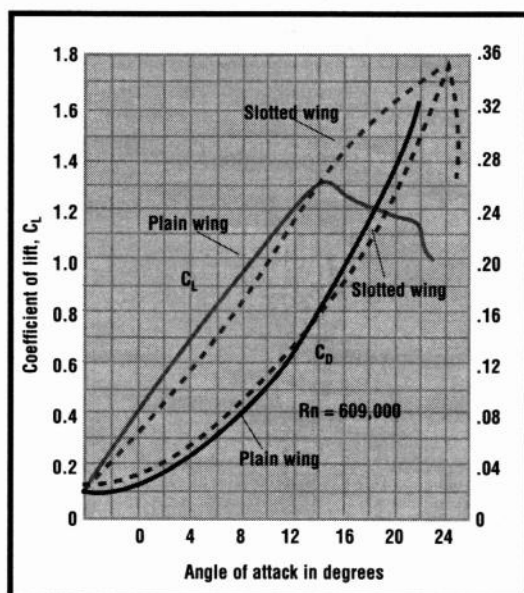

Figure 5.
The benefits of the fixed LE slot.

and a delay in stall to a 9-degree higher AoA, with only a small drag increase.

The retractable versions are self-opening at higher AoAs, but they demand smoothly operating, non-jamming mechanisms and should be linked so that the slats of both wing panels extend simultaneously for obvious reasons. They may also be servo operated.

To this author, the added complexity of the retractable slat is not justified by its benefits. The Crow has full-span, fixed LE slots, as shown in Figure 2.
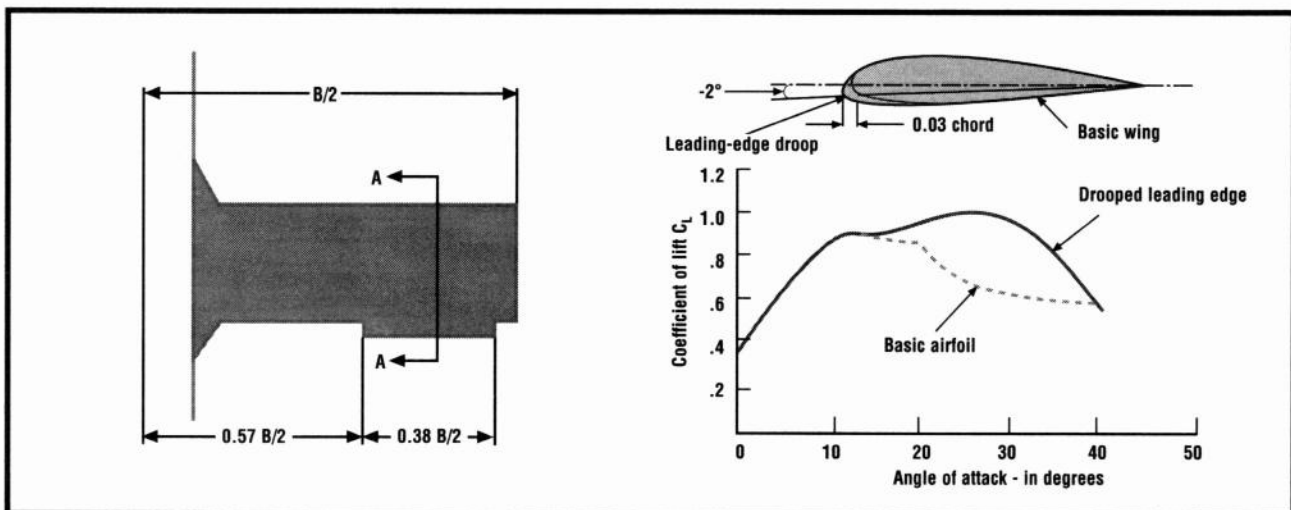

Figure 6.
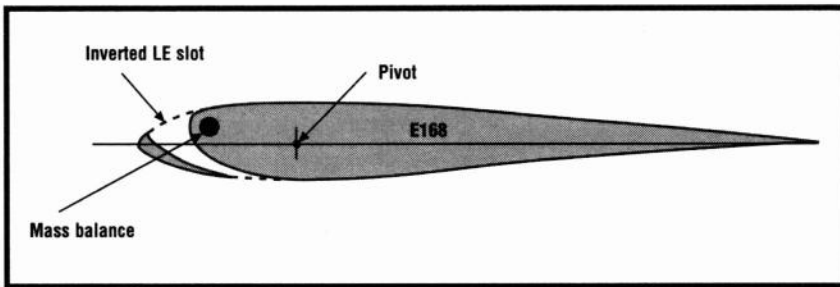*Wing LE modification for improved stall/spin resistance.*

Figure 7.
The Crow's stabilator section.

■ **NASA LE droop.** As shown in Figure 6, these delay the stall by about 8 degrees; they provide extra lift at higher angles of attack; and they have low drag. Used as shown for 38 percent of the semi-span, ahead of the ailerons, they greatly improve aileron control effectiveness at high AoAs. The "droop" was used on the Swift to advantage.

■ **Horizontal-tail LE slots.** To obtain the high AoAs, before the stall, of the wings with LE slots and slotted flaps, a powerful downforce on the horizontal tail is needed to raise the model's nose. The Crane needed inverted LE slots on its horizontal stabilator to achieve this attitude. Similarly, the Crow STOL model's horizontal stabilator is equipped with inverted LE slots as shown in Figure 7.

■ **Slot-lip ailerons.** Illustrated in Figures 2 and 8, these replace nor-mal ailerons when full-span flaps are used. On both the Crane and the Crow, these have proven to be very effective, and they work inverted. At any one time, only one works—that on the inside of the turn; the opposite one lies flat. The raised aileron reduces lift and has into-the-turn yaw. Both are lightly spring loaded to hold them down when they aren't being actuated. With flaps extended, they are even more effective. Raised, the slot effect over the flap is destroyed, reducing flap lift and adding into-the-turn drag. They provide crisp roll control at lower speeds of flap-extended flight—when most need-ed! The dimensions of these slot lip ailerons on the Crow were: width—15 percent chord; length—60 per-cent of semi-span.

■ **Landing-gear design.** Landing-gear design for models with HLDs is thoroughly discussed in Chapter 16, "Landing Gear Design." The "tail angle" (also called the "tip-back angle") must be large enough to permit the model to land at very close to its stall angle of attack and its slowest speed.

■ **Control unit.** Flap operation requires an extra servo, which may be operated by the retract switch on a 5-channel (or more) radio, but this provides only full-up or full-down flap positions—no in between! An auxiliary channel is desirable, controlled either by a three-position snap switch that provides full-up, 20 degrees down and 40 degrees down-flap positions; or a proportional slide switch that per-mits a choice of any flap position from full-up to full-down.

A TRIBUTE

Dick Murray and Ken Starkey—two friends and fellow club members—have test-flown each of this author's new designs. Both are pilots of consummate skills; and both offered valuable, constructive comments on the flight characteris-tics of each model. For lending me their skills and for their friendship, I am deeply grateful. Do try HLDs and drag reduction. Models of this type are highly versatile, and flying them is pure fun—well worth the extra effort their design and con-struction entails. Above all, they are sleek and beautiful. ▲
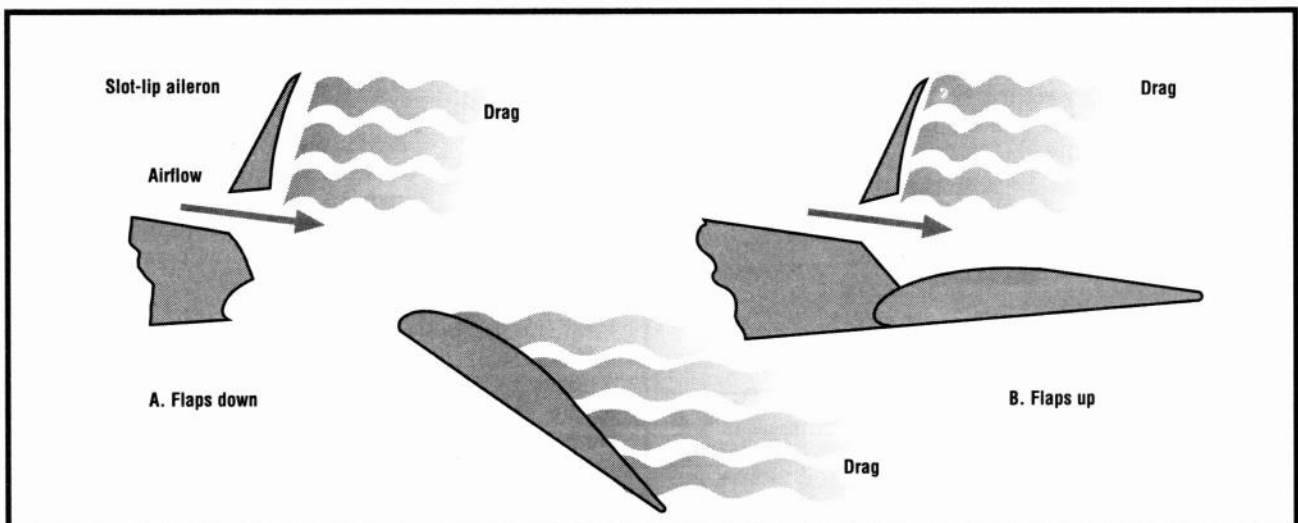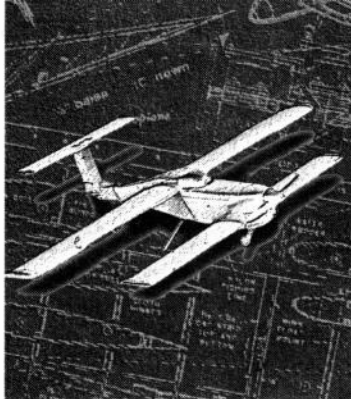

Figure 8.
Slot-lip aileron action.

Chapter 21

Centrifugal Force and Maneuverability

In aerobatics, centrifugal force (CF) imposes both aerodynamic and structural loads on an airplane that may be many times the model's weight. It deserves serious consideration. CF acts at the plane's center of gravity (CG). The center of lift may be ahead of, on, or behind the CG in maneuvers.

■ If the center of lift is ahead of the CG, lift is upward; CF and weight pull downward at the CG. A force couple is created that causes the model to nose *up*, and this assists in the turn or climb.

■ If the center of lift is behind the CG, the force couple will cause the model to nose *down* and resist the maneuver.

■ If the center of lift and CG are vertically aligned, weight and CF are neutralized by lift and do not affect maneuverability.
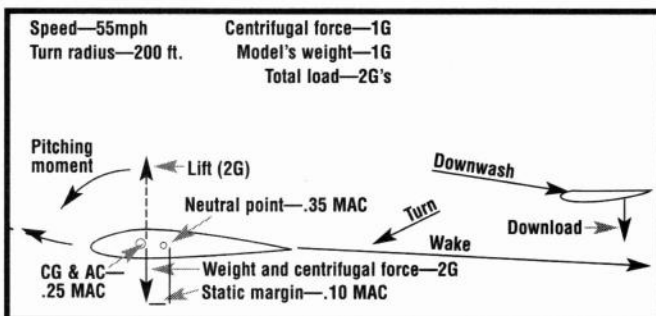
This chapter describes the evaluation of CF and analyzes various center-of-lift/CG positions for conventional (tail-last), tandem-wing, canard and three-surface configurations.

CENTRIFUGAL FORCE EVALUATION

It's easy to evaluate the maneuvering loads brought about by CF. Two important maneuvers will be considered: turns in a vertical plane and turns in a horizontal plane. Most aerobatics involve a combination of these.

■ Turns in a vertical plane—a series of loops. The CF will be evaluated at the bottom of the loop where weight and CF act downward.

■ Turns in a horizontal plane—a steady, level, coordinated turn in which weight acts downward but CF acts horizontally.

VERTICAL MANEUVERS

Assume that a plane flying at 55mph is at the bottom of a continuing 200-foot-radius (400-foot diameter) loop (see Figure 1). The combined weight and CF total 2G's, or twice the model's weight, and this force acts at the model's CG. The increase in the load the wing must support is modest. Had the loop been flown at 90mph, with a 100-foot radius, the CF would have increased to 5.4G's, plus the model's 1G weight, for a total load of 6.4G's.

Referring to Figure 1, the resulting force changes are:

■ **Lift.** The wing's AoA and C_L must increase to provide the additional lift needed.

■ **Drag.** Both profile drag and induced drag increase.

■ **Downwash.** The increased lift coefficient causes an increase in the downward deflection of the downwash striking either the horizontal tail or the aft wings of the tandem, canard, or three-surface configurations.

■ **Pitching moment** (PM). For cambered airfoils, the wing's PM may increase with increase in its angle of attack (AoA). The charts for the airfoils involved must be consulted.

■ **Thrust moment.** If the thrust line is above the CG, a nose-down moment results. If the thrust line passes through the CG, the result is neutral. If it is below the CG, a nose-up moment occurs.

■ **Drag moment.** If the center of lift is above the CG, the increased drag will cause a nose-up effect. If center of lift and CG coincide, the result is neutral. If the center of lift is below the CG, a nose-down action results.

■ **Maximum lift coefficient.** If the combined weight and CF in small-radius, high-speed turns exceeds the wing's maximum lift capacity, a high-speed stall will occur.

■ **Structure.** The model's structure must withstand the substantially increased load without failing.

HORIZONTAL TURNS

See Figure 2. With a plane flying at 55mph in a steady, level, coordinated, 200-foot-radius turn, CF acts horizontally; to provide lift to oppose it, the model must be
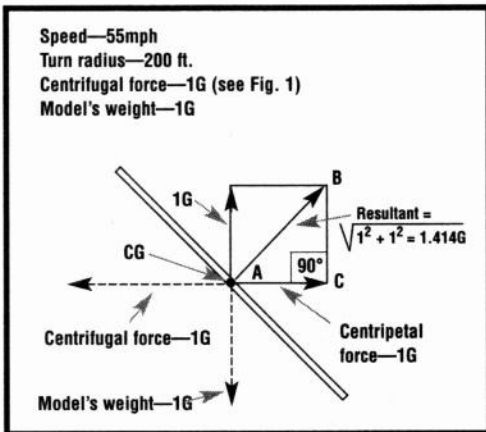

Speed—55mph
Turn radius—200 ft.
Centrifugal force—1G
Model's weight—1G
Total load—2G's

Pitching moment
Lift (2G)
Neutral point—.35 MAC
Downwash
Turn
Wake
Download
CG & AC .25 MAC
Weight and centrifugal force—2G
Static margin—.10 MAC

Figure 1.
Loads in a vertical turn (loop).

Figure 2.
Loads in a horizontal turn.

banked as shown. But the wing's lift must also overcome the model's weight. As in Figure 1, line CF represents 1G, and it must be opposed by a centripetal force of 1G. This results in a force diagram that is solved by vector analysis. In Figure 2, line AC is the centripetal force of 1G and line BC is the model's weight of 1G.

ABC is a right-angle triangle in which our old friend, "the square of the hypotenuse is equal to the sum of the squares of the other two sides" applies. As Figure 2 shows, the result is 1.414G's, and the angle of bank is at 90 degrees to line AB.

Obviously, in terms of turn radii and speeds, the horizontal turn is less demanding than the vertical turn. These comments on lift, drag, etc., for vertical turns, however, do apply to horizontal turns.

CG LOCATION

Figures 3 through 9 illustrate seven possible stable CG locations.

Figures 3, 4 and 5 are for conventional airplanes where only the wing's lift supports the model; the

Figure 3.
Forward CG loading in 2G turns.

horizontal tail controls the wing's AoA and compensates for moments caused by thrust, drag, pitch and CG location.

Figures 6, 7, 8 and 9 display configurations in which two surfaces actively provide lift, share the model's weight and provide additional lift to overcome the various moments listed above.

Elevators for planes shown in Figures 3, 4 and 5 are on the horizontal tail's trailing edge. For the tandem wings shown in Figure 7, elevators may be on the trailing edges of either the fore or the aft wing.

Canard elevators are usually on the foreplane's trailing edge (Figure 8).

For the three-surface designs shown in Figure 9, the elevators are on the horizontal tail's trailing edge.

In all cases, the CG *must* be ahead of the neutral point (NP) for longitudinal stability.

Note the rearward shift of the CG from Figures 3 to 9 as the model's configurations change.

The following analyzes each configuration and its response to CF and other forces, both in level flight and under a 2G load.

■ **Forward CG.** The CG is at 15 percent of the wing's MAC, ahead of the wing's aerodynamic center of lift, which is at 25 percent MAC. The generous static margin of 20 percent MAC ensures that the model will be easy to fly and very stable

longitudinally. In maneuvers, however, a force couple is created; CF and weight acting at the CG pull downward; wing lift at the aerodynamic center pulls upward; both cause the airplane to move away from the loop or turn, resisting the maneuver.

A substantial increase in tail download is required to overcome this. Elevators whose area is 40 percent of the total horizontal tail area will have adequate authority, but at high CF values, they simply can't provide adequate download, and the tail stalls. This limits the model's high-speed, low-radius turning capability and its maneuverability.

The increase in the downward deflection of the downwash striking the horizontal tail does assist, but this brings the tail closer to its stalling angle.
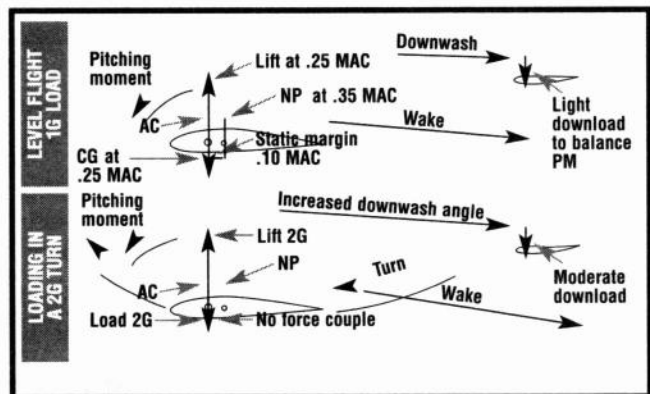

Figure 4.
Loading with CG at .25 MAC in a 2G turn.

■ **CG on the aerodynamic center** (Figure 4). The wing's lift, at its aerodynamic center, is vertically in line with the CG. In turns, CF neither adds to nor reduces the horizontal tail's load.

If the wing's airfoil is cambered, the tail must compensate for the nose-down pitching moment. If it is symmetrical, there is no pitching moment; this increases the horizontal tail's effectiveness. The increase in the downwash angle that results from the wing's increased lift coefficient aids the maneuver.

Elevators of 30 percent of the horizontal-tail area are suggested. The Swift typifies this arrangement.

■ **CG aft of the aerodynamic center** (Figure 5). In this configuration, the CG is slightly behind the
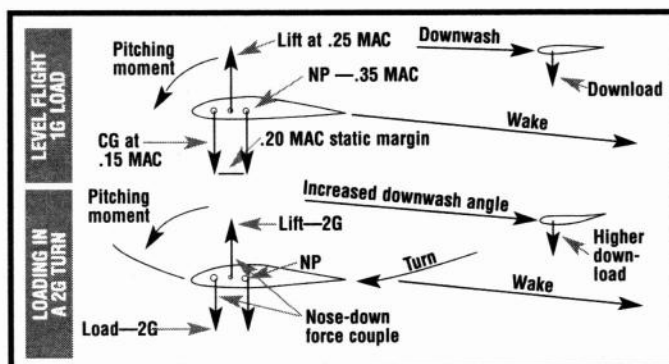
wing's aerodynamic center at the 25 percent MAC location by 2 to 5 percent MAC. A modest increase in the horizontal tail's area of 3 to 5 percent of the wing's area will move the neutral point aft and maintain a healthy static margin of 10 percent MAC.

Under CF loads, the force couple is upward at the aerodynamic center and downward at the CG behind the aerodynamic center, and that helps the elevator action (as does the increase in downwash deflection). An elevator area of 25 percent of the horizontal-tail area is adequate.

LIFTING TAILS
See Figure 6. This type could almost be classified as a tandem-wing model; both wing and horizontal tail share in lifting the model's weight and in compensating for the various moments. It's an old free-flight setup, typified by the late Carl

Figure 5.
CG aft of .25 MAC loading in a 2G turn.

Goldberg's classic Comet design and advocated by H. deBolt.

The lifting tail has a flat-bottom airfoil and is 35 to 40 percent MAC of the wing in area. This moves the NP aft to 45 percent MAC, permitting a CG at 35 percent MAC, well behind the wing's aerodynamic center at 25 percent MAC, but provides a healthy static margin of 10 percent MAC.

Up-elevator reduces the tail's upward lift. CF acting at the CG is behind the center of lift, and the resulting strong force couple actively assists up-elevator action, as does the increased angle of downwash. An elevator area of 20

percent of the horizontal tail is adequate.

The configuration is unsuitable for a model equipped with flaps on the wing. Fully extended, the flaps would:

■ Substantially increase the wing's lift and lift coefficient.

■ Sharply increase the down-ward angle of the downwash striking the horizontal tail, reducing its lift or reversing it to downlift.

■ Move the combined center of lift of the wing and tail forward.

■ Increase the moment arm between this combined center of lift and the CG, augmenting the nose-up force.

The combination of increased wing lift, reduced or reversed tail lift and the increased force

couple between center of lift and CG would render the airplane dangerously unstable in pitch when the flaps were extended.

TANDEM WINGS
See Figure 7. This configuration is shown in the Wasp. Both wings share the lift to
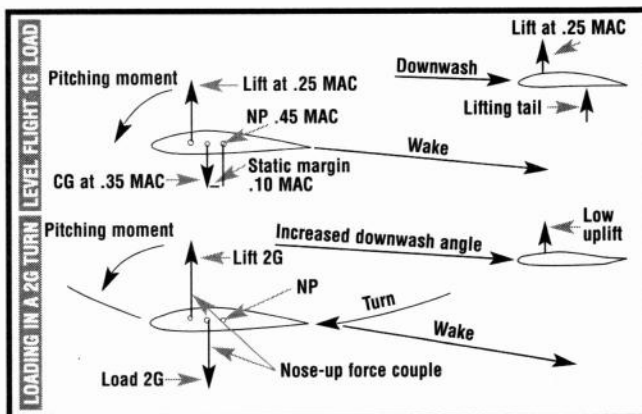

Figure 6.
Lifting tail load in a 2G turn.

support the model, plus additional foreplane lift to compensate for the nose-down pitching moments of both wings' cambered airfoils. The combined center of lift of the two wings is thus ahead of the CG. Application of down-elevator on the foreplane does two things: it increases the foreplane's lift, and the downward angle of the downwash reduces the aft wing's lift. Both act to move the combined center of lift farther forward.

CF acting at the CG aft of this combined center of lift greatly aids the maneuver. In retrospect, the moment arm from CG forward to the foreplane's 25 percent MAC is short. A better option would have been to place smaller elevators on the aft wing's trailing edge, between the vertical surfaces, with ailerons on the foreplane. Flaps, if used, would be required for both wings.
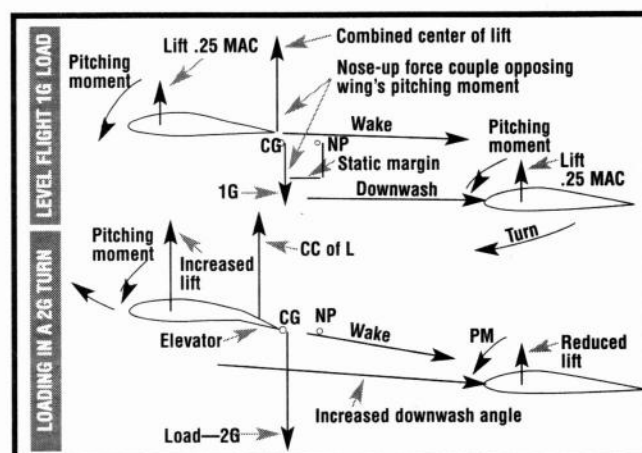

Figure 7.
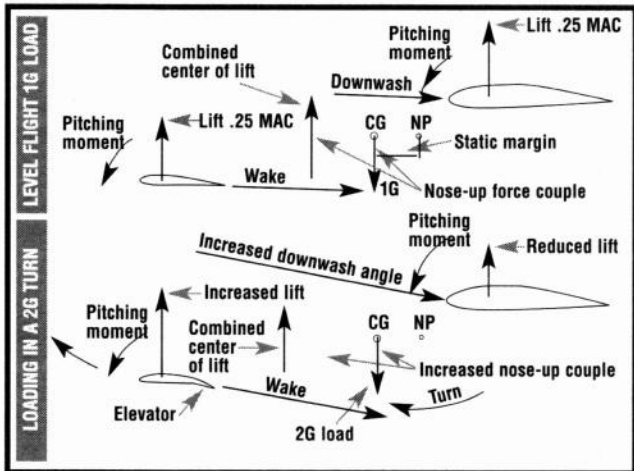**Tandem-wing loading in a 2G turn.**

Figure 8.
Canard loading in a 2G turn.

CANARDS

See Figure 8. Like in the tandem-wing version, the foreplane must lift its share of the model's weight, plus provide additional lift to offset the cambered airfoils' pitching moments; this puts the combined center of lift ahead of the CG. Since the distance from CG to foreplane AC is greater than for the tandem type, the canard foreplane's pitching-moment load is less than for the tandem foreplane.

Depressing the foreplane's elevators increases its lift and increases the downwash deflection; this reduces the rear plane's lift in the portion "shadowed" by the front wing. Both move the combined center of lift forward. Under CF, a greater nose-up force couple

results, and this helps with the maneuver.

The Canada Goose and the Swan had slotted flaps on both fore and aft wings.

THREE-SURFACE DESIGNS

See Figure 9. The Wild Goose shown in the photos illustrates this design. The horizontal tail controls pitch, and both wings have slotted slaps for slower landings. The tail's area moves the neutral point aft, and that permits the CG to move aft as well.

The closer spacing (longitudinally) of the wings results in a short moment arm from CG to foreplane AC. This results in a higher load on the foreplane to overcome the pitching moments of the two wings. The combined center of lift is thus ahead of the CG.

Up-elevator reduces the foreplane's load but does *not* reduce its lift. The combined center of lift moves forward; CF acting at the CG produces a nose-up force couple.

The combined elevator download and the reduced foreplane load are very effective in pitch. The

elevators are sensitive; a ratio of 20 percent elevator area to total tail area is adequate.

INVERTED FLIGHT AND MANEUVERABILITY

Of the seven configurations discussed so far, only Figures 1, 2 and 3 will easily fly inverted. The rest rely on two wings for support. Inverted, these types would not satisfy the two critical requirements for longitudinal stability:

■ The foreplane must stall first.
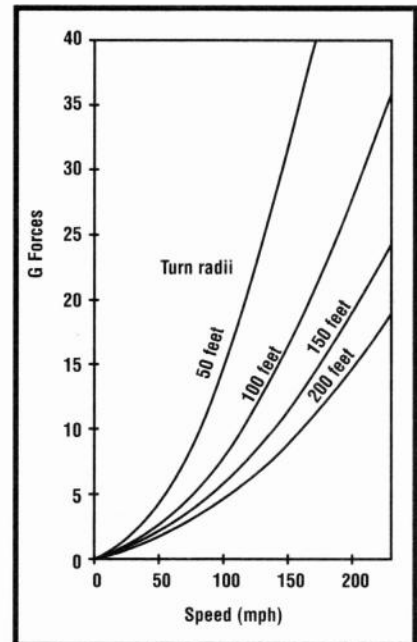
■ The aft plane must achieve zero

Figure 10.
G forces in pulling out of a vertical dive at various speeds and turn radii, including model's' 1G weight. Example: at 100mph in a100-foot turn radius, G forces are 7.7 times the model's weight.
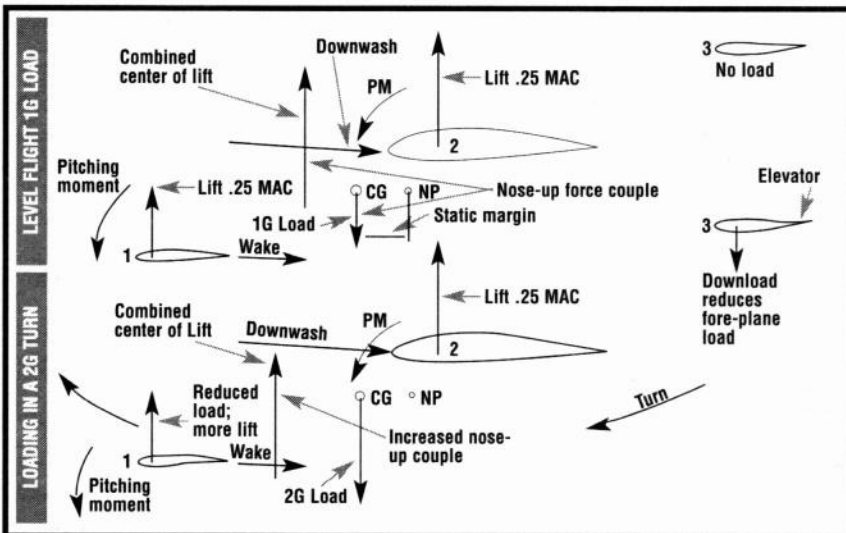
lift first. For conventional tail-last types, optimum maneuverability is obtained by having a symmetrical airfoil and ensuring that thrust, drag and lift forces run through the CG. This arrangement neutralizes the disturbing moments and allows the tail full effectiveness, particularly if it is T-mounted.

Except for its airfoil, which is semisymmetrical, the Swift's design complies with these stipulations. ▲

Figure 9.
Three-surface loading in a 2G turn.
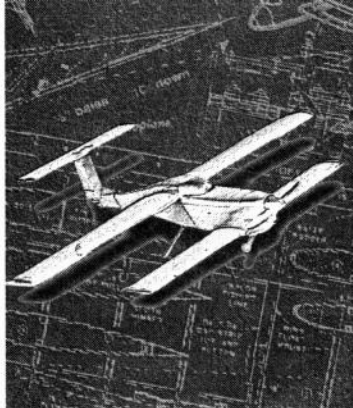
Chapter 22

Canards, Tandem Wings and Three-Surface Designs

History repeats itself. The first successful powered flights were made by canards; subsequent designs incorporated both a canard foreplane and a tailplane behind the wing, i.e. three surfaces.

Eventually, the wing and rear tail versions predominated, and they're now the conventional configurations. Recently, however, largely owing to Burt Rutan's efforts, the canard, the tandem-wing and the three-surface versions have reappeared (Figure 1). Today, Burt's latest designs are more conventional, but still unique, and in this chapter, I'll discuss the design of these three configurations.

The Swan canard pusher.

ADVANTAGES

■ **Increased safety.** For well-designed, full-scale canard, tandem-wing and three-surface aircraft, the major advantage of their design is that it frees them from the too-often-fatal, stall-spin-at-low-altitude crash. Though the foreplane may stall, the main wing does not.

■ **Shared load; reduced main-wing area.** In a conventional aircraft, the wing does all the work; the horizontal tail is lightly loaded (downward in most cases) and simply controls the wing's AoA. On these three types of front-wing aircraft, their forward surfaces work hard and share the load with the main wing, which may, as a result, have a reduced area.

■ **Main wing spar may be out of the way** at the rear of the cabin; the conventional version's spar goes through the cabin and interferes with passenger seating (particularly true of low- and mid-wing types).

■ **Smaller, lighter, more compact airplane**—achieved by dividing the required wing area between two lifting surfaces.

DISADVANTAGES

■ **Heavily loaded foreplane.** For stability, the foreplane must be much more heavily loaded (in terms of ounces or pounds per square foot of wing area). The foreplane's loading controls the aircraft's stall speed, which is considerably higher than the main wing's stall speed. Canard and tandem-wing types take off and land faster and need a longer run-way than conventional aircraft. The three-surface design is better in this respect because its foreplane loading may be reduced, but three surfaces mean more interference drag.

■ **Limited aerobatic capabilities.** The high foreplane loading, combined with the inability to stall the aft wing, limits the aerobatic capabilities of these three classes. (See Chapter 4, "Wing Loading Design.")

AIRFOIL SELECTION

For all three types of forward-wing aircraft, airfoil selection is very critical. There are three broad categories of airfoil: heavily cambered (such as E214); moderately cambered (such as E197); and no-camber, symmetrical type (such as E168). (See Figure 7 in Chapter 1, "Airfoil Selection.")

Figure 2 compares lift with AoA curves for these three airfoils. Note that, though the heavily cambered E214 stalls at a lower AoA, it starts lifting at a higher *negative* angle than the other two. The symmetrical E168 starts to lift only at a positive angle, and its max C_L is the lowest of all three. (See the appendix for the section characteristics of these airfoils.)

Since all three configurations have both forward and main wings sharing the lift, two requirements are of *critical* importance for successful, stable flight:

■ The front wing *must* stall before the main wing stalls. If the main wing stalls first, the scenario depicted in Figure 3 will result; at low altitude, a crash is inevitable.

■ The main wing *must* arrive at its angle of zero lift before the foreplane achieves zero lift. If the foreplane ceases to lift while the main wing still lifts, the behavior shown in Figure 4 results.
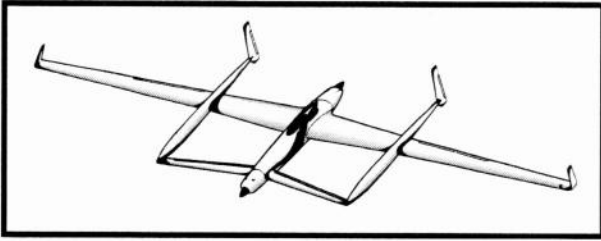
Figure 1.
Rutan's around-the-world Voyager.

With these considerations in mind, look again at Figure 2. Obviously, airfoil E214 would be an excellent choice for the front wing. Its early stall and high *negative* angle of zero lift satisfy both requirements, and its stall is gentle.

For the main wing, airfoil E197 would again be excellent. Its higher AoA at the gentle stall and its lower *negative* angle of zero lift comply with both manda-tory require-ments. E168 would not be suitable for either front- or main-wing air-foils, but it would be a good section for the horizontal tail-plane of a three-surface design.

An airfoil's stall pattern at C_L max and at the wing's flight Rn is another important consideration. Obvi-ously, for a canard or tandem-wing fore-plane to have sudden-lift-loss or sharply stalling airfoils invites

trouble. In the landing flare, if the foreplane were to stall suddenly, landing would be very hard and would probably damage the nose-wheel landing gear.

For the three-surface airplane with a horizontal tail and elevators, a sharp foreplane stall is desirable to prevent up-eleva-tor action from stalling both the front and main wings. Elevator action would pre-vent a sudden nose drop. See Eppler E211—a foreplane airfoil with a sharp stall at low Rn—in the appendix. Note the reduction in the negative AoA of zero lift as Rn is reduced.

Using slotted flaps on the foreplanes of canard and tandem-wing models for pitch control has three effects (see Figure 5):

- The stall angle is reduced.

- The *negative* angle of zero lift is increased.

- C_L max is increased substantially.

REYNOLDS NUMBERS, ASPECT RATIO AND PLANFORM

High aspect ratios reduce the stalling angle (desirable for fore-planes) but result in lower Rns, particularly at landing speeds.
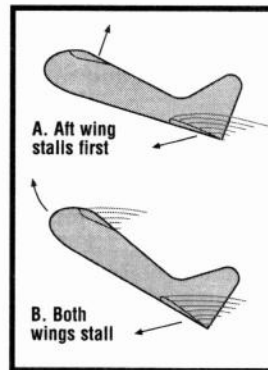

Figure 3.
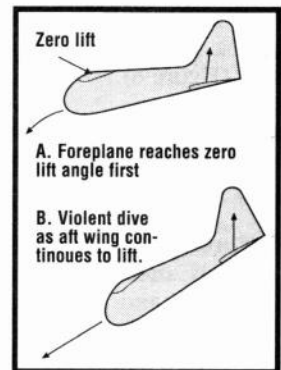*Nose-up pitch as aft wing stalls first.*

Figure 4.
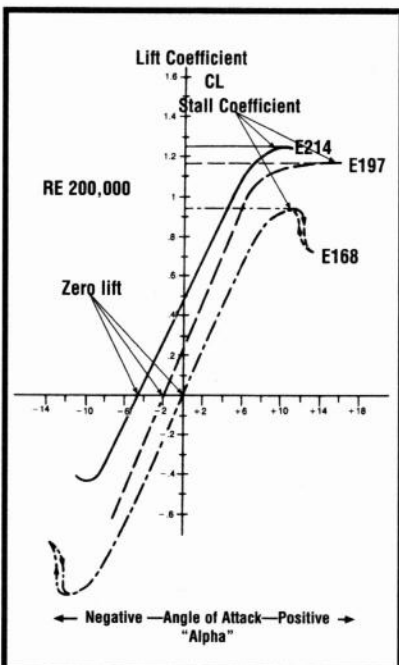*Steep dive as foreplane hits zero-lift angle first.*

Chords of less than 5 inches are to be avoided. (For more on these subjects, refer to Chapter 1.)

Low aspect ratios increase the stalling angle (desirable for the main wings) of all three types. Shorter main wingspans improve roll response.

A mild forward sweep on the foreplane promotes root-stalling first (see Chapter 5, "Wing Design"). The result is a gentle, progressive stall as the angle of attack increases. Such forward sweep should not exceed 5 degrees on the 1/4 MAC line. On a three-surface design, forward sweep would also benefit the horizontal tailplane.

DOWNWASH AND TIP VORTICES

Downwash is thoroughly dis-cussed in Chapter 7, "Horizontal Tail Incidence", and charts for esti-mating downwash angles are provided. Each of the three, for-ward-wing aircraft is affected by downwash.
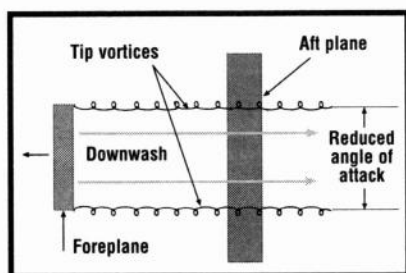

Figure 2.
Lift curves of three airfoil types.
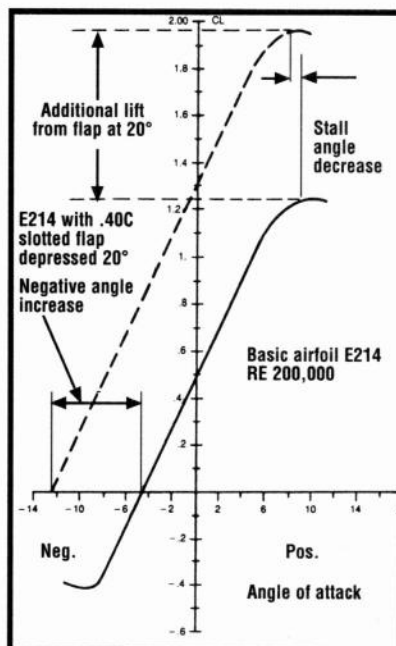
Figure 5.
Impact of a 40% chord slotted flap deployed to 20 degrees on airfoil section 214.

Figure 6.
Downwash impact on a canard.

Figure 7.
Downwash impact on a tandem wing.

■ **Canards:** foreplane downwash impacts on a portion of the aft wing (equal in span to that of the foreplane), reducing the angle of attack and lift in the downwashed area (Figure 6).

■ **Tandem-wing aircraft:** the whole span of the aft wing is similarly affected (Figure 7).

■ **Three-surface models:** the main plane is affected as in the canard (Figure 6); and the horizontal tail is affected by the downwash from that portion of the main wing that's "shadowed" by the foreplane downwash. The reduced AoA of the "shadowed" portion of the main wing may be compensated for as follows:
—For tandem wings of equal span: for level flight at the designed cruising speed, the aft wing's AoA should be increased by the downwash angle generated by the foreplane.
—For canards and three-surface airplanes: shadowed portions of the main wing should have an increase in AoA that's equal to the fore-
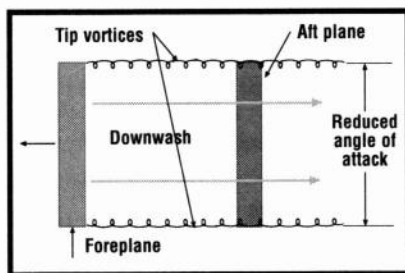
plane's level-flight downwash angle. The part of the wing that's out of downwash is left at the AoA calculated to produce adequate lift. This calls for a "jog" in the wing and was used on the Swan.

A variation of this is to use the NASA droop for that part of the wing that's out of downwash, so that the inboard ends of the droop are just behind the foreplane tips.

A simpler method, where the foreplane span is roughly half that of the main wing, is to increase the whole main wing's AoA by half the foreplane level-flight downwash angle. The main wing outboard portions will have higher lift coefficients, closer to the stall. The Canada Goose used this method.

A third method is wing washout with increased root AoA and reduced tip AoA. An accurate built-in twist is needed, but it results in an increase in wingtip stall margin and is stabilizing on a sweptback main wing.

In all cases, the net lift should equal the calculated lift needed.

To avoid the impact of foreplane-tip vortices on the main wing, a vertical gap between foreplane and main plane of half the aft wing's MAC is suggested—either the foreplane low and the main plane high, or the reverse may be used. The foreplane-tip vortices will then pass under or over the main wing. Longitudinal separation or "stagger," between ¼ MAC points of each wing, of two to three times the aft wing's MAC, is appropriate.

For the three-surface design, it is suggested that the horizontal tail be "T"- mounted on the fin where it will be more effective, and the stagger be 1 to 2 times the aft wing's MAC.

LOGICAL DESIGN STEPS
■ **Power and control unit selection.** The power and control units together weigh 50 percent or more of most models' total weight. The first step in design is to choose these units and obtain their weights.

■ **Overall weight estimation.** Obtaining a rough preliminary weight estimate while the model is still in the conceptual stage is essential but not easy. The data on weight estimating in Chapter 13, "Stressed Skin Design and Weight Estimating," will help. When the model's size and proportions have been established, a more accurate weight appraisal is advisable. Chapter 5, "Wing Design," also provides insight into obtaining this estimate.
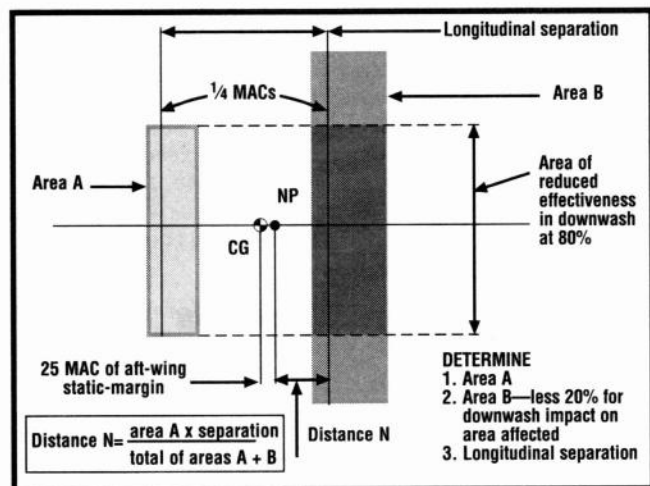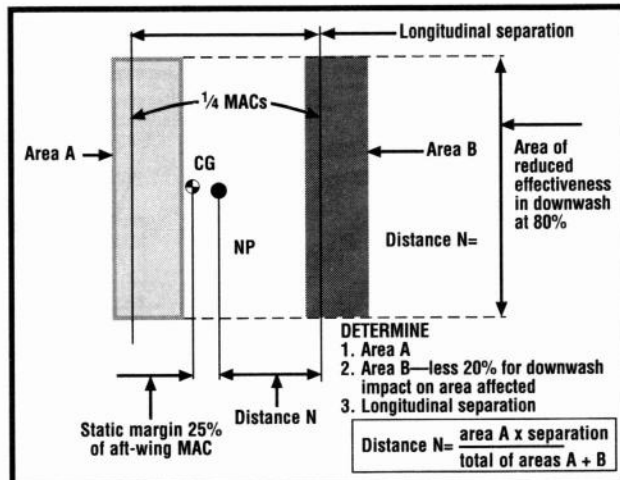

Figure 8.
Locating a canard's NP and CG.

Figure 9.
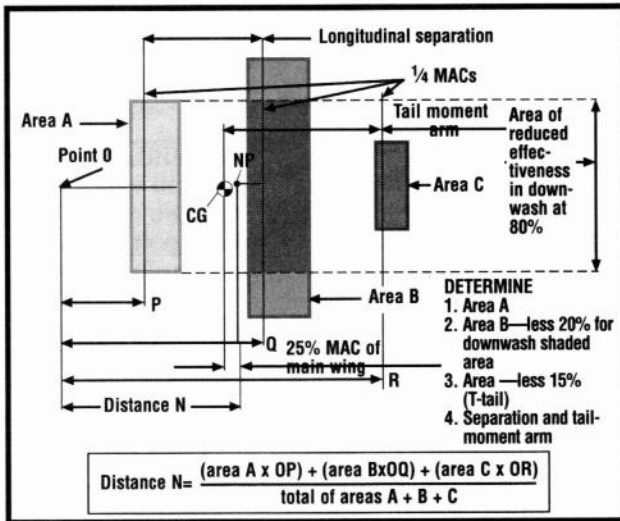*Locating tandem-wing NP and CG.*

Figure 10.
Locating three-surface design NP and CG.

■ **Wing loading selection.** The type of performance desired governs the choice of wing loadings. Chapter 5 suggests wing loadings in ounces per square foot of wing area.

If the design is to incorporate flaps, then higher wing loadings are in order. When deployed, their additional lift and drag will provide reasonable landing speeds. With weight and wing loading established, the wing's total surface area is easily calculated:

Wing area (sq. in.) =

$$\frac{\text{Weight (oz.)} \times 144}{\text{Wing loading (oz./sq. ft.)}}$$

■ **Level-flight speed estimate.** This is essential in determining the angles of attack of the fore and aft wings.

■ **The neutral point and CG location.** The NP concept is discussed in the Chapter 6, "CG Location." For the three types of forward-wing models, both CG and NP will fall somewhere between the two lifting surfaces. Precisely calculating their locations is very complex and beyond the scope of this article. In full scale, the calculations are confirmed by wind-tunnel tests or actual flight tests with the CG at various locations.

A simplified method is proposed; it considers areas and their separa-

tion and effectiveness. Figure 8 covers NP and CG locations for canards, Figure 9 for tandem-wing designs and Figure 10 for three-surface models. The normal static margin for stability is 10 percent of the main wing's mean aerodynamic chord (MAC). Use of a 25-percent static margin as suggested leaves a 15 percent margin of error. Test-flying the model with cautious rearward CG movement will confirm your calculations.
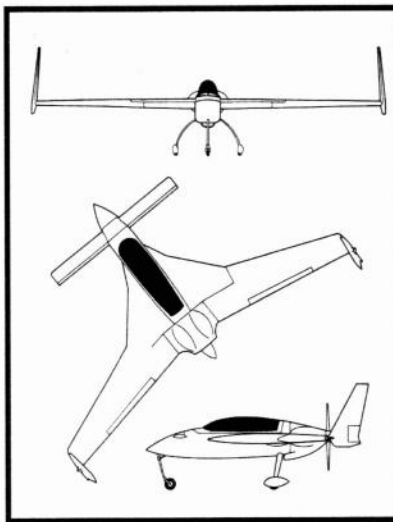

Figure 11.
Three-view drawing of the Rutan Long-EZ.

■ **Sizing of fore and aft wings.** The total wing area, having been established, must be divided between the two lifting surfaces.

CANARDS

From the discussion of NP and CG locations, it is apparent that the smaller the foreplane, the farther back NP and CG will be and vice versa. The area relationship between the two lifting surfaces determines NP and CG.

The heaviest component is the power unit. Its location dictates the

area relationship of fore and aft wings. A pusher-engine design would require an aft CG, a small canard and a large wing. A front-engine design would reverse this situation.

If flaps are used, they must provide balanced lift when extended. Too much additional lift from either fore or aft wings would result in very serious pitch problems—either a dive or a stall. Obviously, both sets of flaps must be extended simultaneously for balance.

With a small canard of 15 percent of the aft wing in area, flaps on the aft wing would be much more powerful than those on the foreplane. Another disadvantage of a small canard and rearward CG is the reduction in moment arm to the MAC of the vertical tail surface(s); it necessitates very large vertical areas. Burt Rutan solved this problem by using aft-wing sweepback and placing the vertical surfaces at the wingtips (Figure 11). This substantially increases the moment arm. The Canada Goose design, with a modest 5 degrees of aft-wing sweepback, had the same philosophy applied to it.

Sweepback reduces lift. As model airplane designer John Roncz put it, "You get around 14 percent more lift per degree of angle of attack at zero sweep than at 30 degrees of sweep."
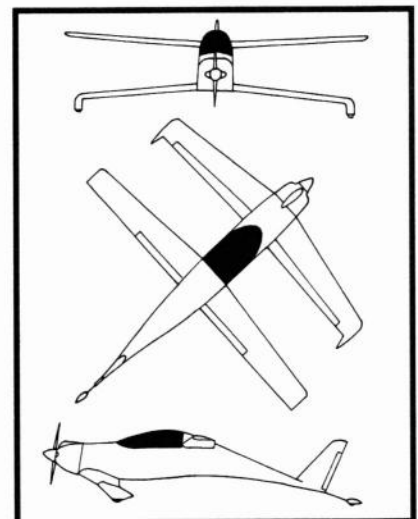
The Swan had a straight aft wing,

Figure 12.
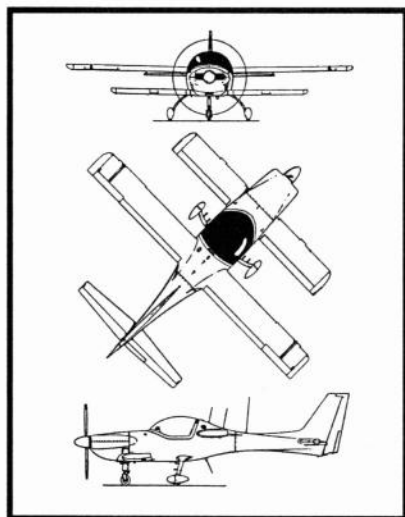*Three-view drawing of the Rutan Quickie.*

Figure 13.
Roncz's Eagle three-surface trainer.

but its vertical surfaces projected behind the wing. Twelve ounces of ballast were needed to correctly position its CG—as had been anticipated after doing the "Balancing Act" (see Chapter 6) for this model. The minimum canard area is 15 percent of that of the aft wing. For a front-engine aircraft, such as the ill-fated "Pugmobile," a foreplane area of close to 60 percent was used.

The Canada Goose had 31 percent foreplane; the Swan had 37 percent. Using a foreplane of 30 percent as an example, total wing area would be 130 percent.

For a total wing area of 600 square inches, foreplane area would be:

$$\frac{30 \times 600}{130}$$

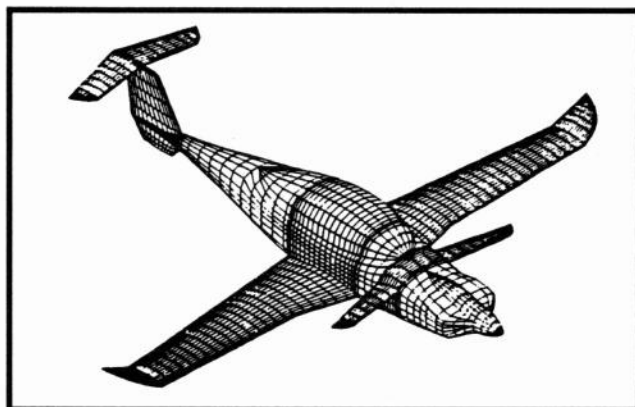or 138.5 square inches; and aft wing area would be:

Figure 14.
Rutan model 81 Catbird (VSAERO model); note three surfaces.

$$\frac{100 \times 600}{130}$$

or 461.5 square inches in area.

The designer needs to take the area relationship into consideration.

TANDEM WINGS
This type has wings with close to equal area. The NP and CG are well forward. A pusher engine *behind the aft wing* would present an impossible CG problem.

Rutan's Quickie (Figure 12) illustrates a front-engine tandem-wing version, with its vertical tail mounted on an extension of the fuselage.

The Wasp is another tandem-wing version. The pusher engine is just behind the front wing. The aft wing and vertical surfaces were supported on booms. This model was very stable, but it had no flaps owing to its low wing loading.

THREE-SURFACE AIRPLANES
The comments on wing sizing for a canard apply to the fore and main planes of the three-surface type. The presence of a horizontal tail causes both NP and CG to move rearward (compared with a canard). The tail's elevators provide pitch control. Slotted flaps on both fore and aft planes permit higher wing loadings with reasonable landing speeds.

Figure 13 shows John Roncz's "Eagle"—a successful trainer that proved safe and easy to fly. Its forward wing area is 67 percent of the main wing area, and both wings are equipped with slotted flaps.

Rutan's "Catbird" (Figure 14) is another three-surface design. Note the slight forward sweep of both canard and horizontal tail. The Piaggio P180 "Avanti" is a twin-pusher-engine, three-surface, slotted-flap airplane (Figure 15). The author's "Wild Goose" was built according to the design approach outlined in this

chapter and flies very well. All four illustrate the added flexibility offered by this three-surface configuration.

■ **Aspect ratio and planform selection.** In addition to determining the areas of the wings, you must also select their aspect ratios and planforms as previously discussed.

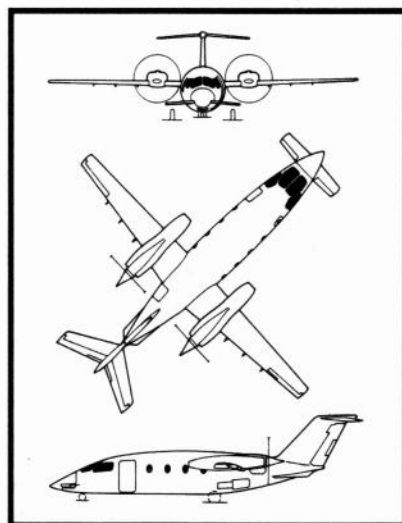■ **Longitudinal and vertical separation.** Longitudinal separation

Figure 15.
Piaggio P 180 Avanti three-surface twin.

(stagger) measured from the 25-percent-MAC points ranges from 1 to 3.25 times the aft wing's MAC.

Vertical separation (gap) should be ½ the aft wing's MAC as discussed.

Tail surfaces of a three-surface design should have a tail-moment arm as outlined in Chapter 7. A T-tail design is favored.

■ **Airfoil selection.** As previously explained, this is critical for stable flight. Additional information and formulas can be found in Chapter 1. The horizontal tail airfoil of a three-surface design should be of symmetrical section

LEVEL FLIGHT
In level flight, at the selected cruising speed, the fore and aft wings must support the model's weight. The calculation of the weight distribution, leading to loadings for both wings, is shown in Figure 16. The foreplane must, however, support
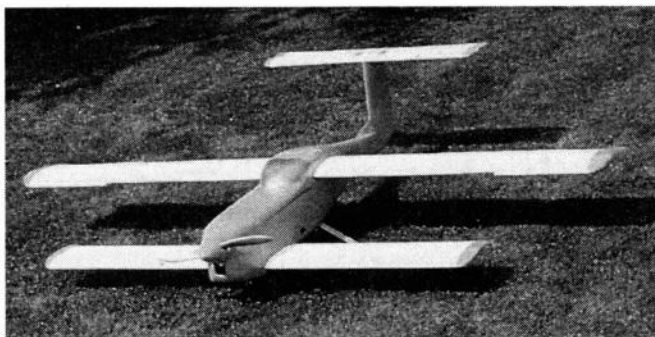
The Wild Goose, a successful three-surface design.

an additional load beyond that resulting from weight alone. This results from:

■ The fore and aft wing's pitching moments always being nose-down or negative.

■ Propeller thrust loading.

■ Drag moments of both fore and aft wings.

Explanation and evaluation follows:

Pitching moments are explained in Chapter 1, and Formula 10 of Chapter 1 permits the calculation of these moments in inch-ounces. Symmetrical airfoils have no pitching moment.

If the propeller thrust is above an imaginary horizontal line drawn through the CG, a nose-down (or negative) moment results. Below that horizontal line, thrust produces a nose-up moment that reduces the foreplane load. If the CG is on the thrust line, there is no thrust loading. The thrust, in ounces, required to propel the model at the design's level flight speed is difficult to evaluate; an estimate would be 40 percent of the model's gross weight. For a weight of 100 ounces, thrust would be 40 ounces.

Figure 17 provides formulas for calculating the wing pitch and thrust-related foreplane loads in ounces. Fore- and aft-plane drag moments consist of the total of profile and induced drags, in ounces, multiplied by the distance, in inches, the wing's ¼ MAC is above or below the CG. If it's above the CG, the moment is nose-up, or positive, and below it, it is nose-down, or negative

(see Formulas 5 and 9 of Chapter 1).

Figure 18 provides simple formulas for establishing the effect of drag moments on the foreplane load in ounces. The total foreplane load is composed of its share of the model's weight plus the net sum of the moment source loads, pitching moments, thrust moments and drag moments (in ounces). Both thrust and drag loads may be positive or negative; take care to identify each so that the net value will be correct.

LIFT COEFFICIENTS

Having determined the wings' areas in square inches and their loadings in ounces, the level-flight design speed estimated (see Formula 7 in Chapter 1) permits calculation of the lift coefficients required for each wing's airfoil. Applying "Special Procedures" A and B will determine the angles of attack to provide those lift coefficients.

Decide which of the procedures will be used to compensate for the reduction in AoA caused by the downwash affecting the aft wing behind the foreplane.

The foregoing provides conditions for level flight at the design speed; any variations from that speed will require the same trim adjustments as for a conventional model.

■ **Stability test.** Two points of critical impor-

tance for longitudinal stability are:
—The foreplane must stall first.
—The aft plane must hit zero-lift first.

Now that the angles of attack of both wings have been calculated, it is time for this test:

Using "Special Procedure" C in Chapter 1, determine the stalling angle for each wing and the zero-lift angles from the airfoils' curves at the landing speed Rns.

Compare the spread from AoA to the stalling angle, but *before* estimating the downwash compensation. Raising the foreplane's lift by lowering its flaps will bring it to its stall attitude; the increased lift produced by both the foreplane and its flap will increase the angle of downwash, increasing the aft wing's stall margin, but only for that portion of the aft wing in the foreplane's downwash; that part out of downwash isn't affected. If your foreplane's calculated angle of attack is 3 degrees and it stalls at 12 degrees, there's a spread of 9 degrees. With an aft wing at 1 degrees, stalling at 14 degrees, the spread is 13 degrees so that the foreplane stalls first.

Similarly compare the spread from zero-lift angles of attack to your calculated angles for both wings. That of the foreplane should be substantially higher than that of the aft
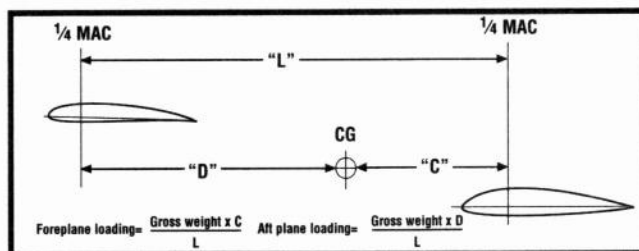

Figure 16.
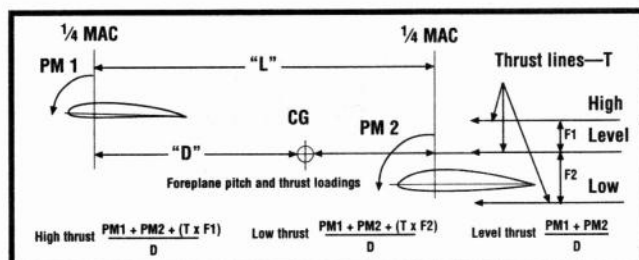*Calculation of wing loadings due to weight only.*

Figure 17.
Additional foreplane loading from wing pitching moments and thrust.

plane. As the foreplane moves toward zero lift, its downwash angle is reduced, increasing the aft wing's lift in the downwashed area and increasing the spread from zero lift to actual AoA.

Eppler E214 has a zero-lift angle of minus 4.75 degrees; if set at 3 degrees, as above, the spread is plus 3 degrees to minus 4.75 degrees, or 7.75 degrees. Eppler E197 has a zero-lift angle of minus 2 degrees. Set at plus 1 degrees, the spread is plus 1 degree to minus 2 degrees or 3 degrees, leaving a healthy margin of 4.75 degrees.

THREE-SURFACE AIRPLANE

This type presents more options than either canard or tandem wing configurations as regards the lift distribution between all three surfaces.

1. The canard and main wing provide all the lift needed. The horizontal tail provides no lift at the selected speed, but its elevators control pitch and trim.

2. Have the canard provide most of its share of the needed lift with the horizontal tail providing a compensating download.

3. Have all three surfaces share the lift. This author's choice would be "1" above—canard and main wing doing all the lifting. Calculation of wing loads would be that for canards and tandem wings described previously.

■ **Unique behavior of the three-surface configuration.** Flight tests of the Wild Goose disclosed unique behavior that relates directly to the three options outlined above. Option 1 had been selected for this model. During its design, the airplane's wing loadings were calculated to be 46 ounces. per square foot for the foreplane and 22 ounces. per square foot for the aft plane in level flight at 60mph.

The foreplane's loading consisted of 18 ounces. per square foot for its share of the model's weight, plus 28 ounces per square foot due to the nose-down load from the airfoils' pitching and the airplane's thrust and drag moments. This high foreplane loading was of concern; but slotted flaps on both fore and aft wings were calculated to bring takeoff and landing speeds to reasonable levels.

During test flights, two unusual characteristics became very evident:

Figure 18.
Foreplane loading from fore and aft wing-drag moments.

$$\text{Foreplane load} = \frac{(\text{Drag -\#1 x P}) + (\text{Drag +\#2 x Q})}{D}$$

■ Elevator pitch control was *very* sensitive.

■ Landing speed, *flaps-up*, was more in keeping with the aft wing's lower loading and comparatively slow—an estimated 25mph.

The explanation of this surprising behavior was reasoned as follows: a conventional, tail-last, airplane with its CG well ahead of its wing's center of lift requires a tail-down load (up-elevator) for level flight. The CG of the three-surface design is well ahead of the aft wing's center of lift, and in level flight, the
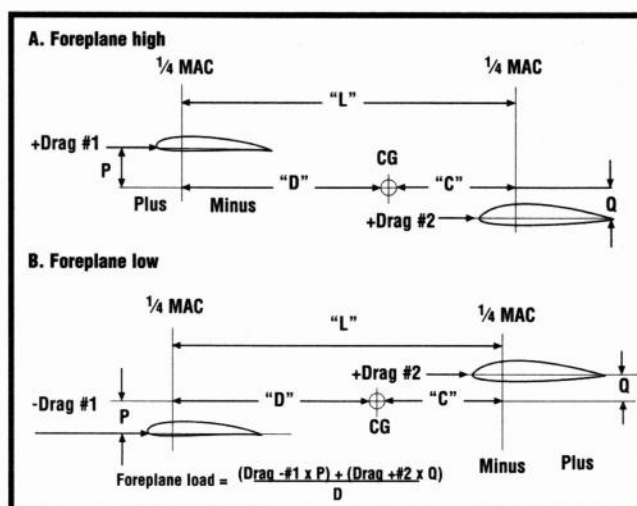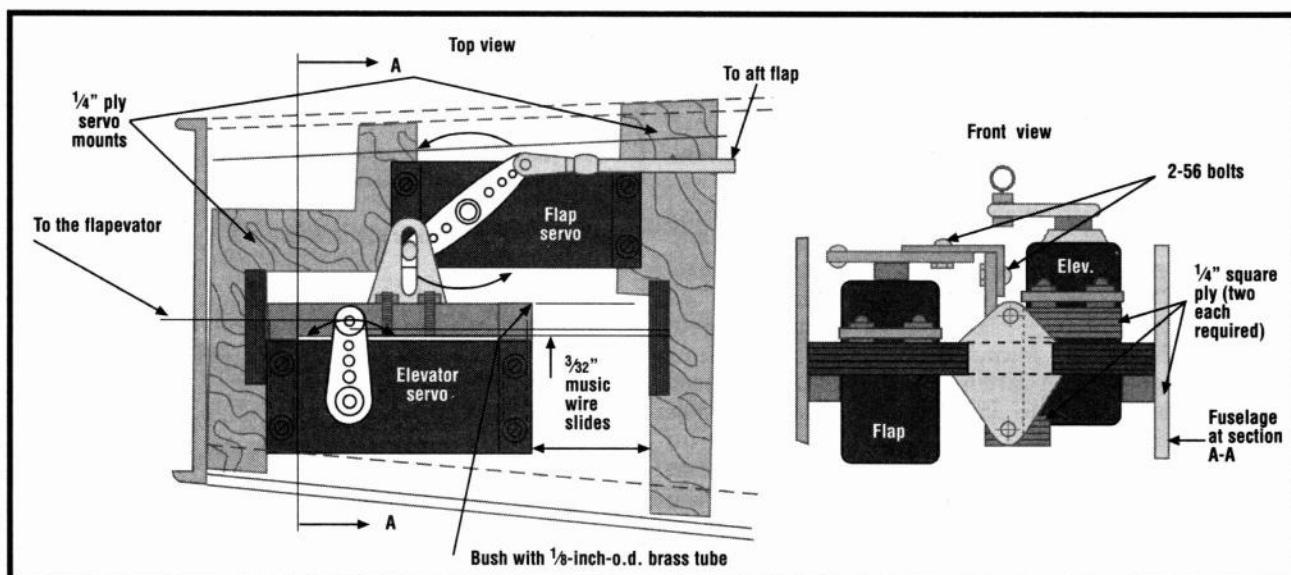

Figure 19.
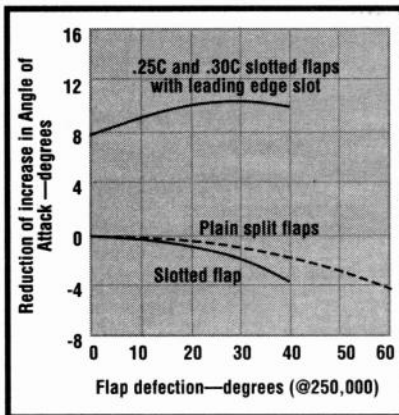*Elevator-flap servo installation.*

Figure 20.
The effect of flaps and leading-edge slots on the angle of maximum lift.

foreplane's lift provides the balancing upward lift. Up-elevator downloads the tail and unloads the foreplane, reducing its wing loading substantially. The foreplane's *surplus* lift is then adding to the up-elevator action, causing the elevator sensitivity.

This results in a very beneficial reduction in landing and takeoff speeds, both flaps-up and flaps-down. This unique behavior has an impact on the three options listed above.

Option 1 is considered above; option 2 would reduce the foreplane's wing loading, its angle of attack, its lift coefficient and its downwash angle. The aft wing's loading would increase, requiring an increase in its angle of attack. This would bring both wings' airfoils closer to dangerously unstable conditions, but it could reduce elevator sensitivity.

Option 3—having the horizontal tail lift upward—would add to the foreplane's loading and would result in even greater elevator sensitivity.

In this author's opinion, option 1 is best. Elevator sensitivity may be overcome by use of the elevator's *low* dual rate, or by reducing the elevator's area to 20 or 25 percent of the horizontal tail's area instead of the Wild Goose's 40 percent.

■ **Longitudinal control methods.** The dominant pitch control for canards is a slotted flap on the canard. Another method is a flap on the foreplane and simultaneous up or down action of ailerons on

the aft wing. The major method for tandem wings is a plain flap of full or partial span on the foreplane. The horizontal tailplane's elevators are the sole pitch control for three-surface designs.

If option 1 is chosen and fore and main planes provide the necessary lift, the horizontal tailplane's AoA should be zero degrees to the downwash from the main wing. That downwash angle is based on the level-flight lift coefficient generated by the main wing, which is, itself, in the foreplane's downwash! Chapter 7 provides charts for estimating downwash.

■ **Directional control.** Chapter 9, "Vertical Tail Design and Spiral Stability," provides the basis for obtaining good directional control. For tandem-wing and three-surface models, the moment arm from CG to MAC of the vertical tail surfaces is large enough to permit reasonably sized surfaces.

Canards, particularly those with small foreplanes and pusher engines, do not have adequate moment arms. Recourse is:
—Larger vertical surfaces
—Booms or fuselage extensions supporting smaller surfaces.
—Aft wing sweepback and wingtip vertical surfaces.

FLAPS
Flaps were previously mentioned, and their limitations were briefly outlined. Since both fore and main wings share the provision of lift, the additional lift provided on flap extension *must not upset* the lift distribution between the wings. Too much lift from either wing would result in dangerous nose-up or nose-down pitch. Both sets of flaps must be lowered simultaneously for the same reason.

Both of this author's canard designs—the Swan and the Canada Goose—had slotted flaps on both wings. The foreplane flaps also provided pitch control as "flapevators." On both models, one servo actuated the foreplane slotted flap for pitch control, but it was mounted on a slide that permitted it to move backward under control of a second fixed servo (Figure 19), lowering both the fore and aft plane flaps simultaneously—foreplane flaps to

20 degrees deflection and aft-plane flaps to such deflection as balanced the increased foreplane lift.

Slotted flaps provide their maximum additional lift at 40 degrees deflection so that the foreplane flap, still under control of the first servo, may move up to neutral or down to the full 40-degree deflection from its 20-degree position for pitch control. Deflecting the foreplane flap results in a substantial increase in downwash on the aft wing, reducing its lift and that of the aft flaps in the area "shadowed" by the foreplane's downwash.

Any attempt to calculate the aft flap deflection angle to balance the front flap's 20-degree deflection would have been very complex. Instead, cautious flight tests were performed, progressively increasing aft flap deflection on each flight, until balance was achieved. Bear in mind that the foreplane flap could be raised or lowered to correct any minor imbalance, and if the imbalance was major, retracting both sets of flaps would restore the model to normal, flaps-up, flight. This worked; the Swan's aft wing slotted flaps, of partial wingspan, were extended to 35 degrees in balancing the foreplane's full-span slotted flaps deployed to 20 degrees.

In flight, lowering the flaps caused the model to "levitate"—at much slower speed, but with no up or down pitch—and the foreplane flap continued its function as
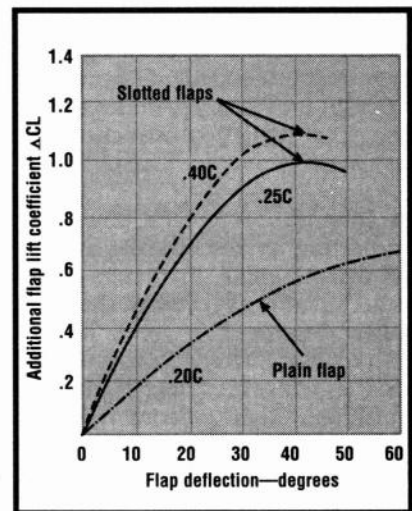

Figure 21.
Additional flap C_L example: .40 slotted flap depressed 20 degrees provides $\triangle C_L$ of 0.80 to lift of basic airfoil section.

elevator under control of the first servo. Almost full foreflap deflection was needed, in ground effect, to raise the nose for a gentle landing.

Flap deflection reduces the stalling angles of both fore and aft wings and greatly increases the foreplane's angle of zero lift (Figure 20). For three-surface designs, the same comments regarding balanced flap lift and simultaneous extension of both sets of flaps apply. However, the foreplane flap serves only as a flap; pitch control is effected by the tailplane's elevators so that the foreflap may be deflected 40 degrees.

Slotted flaps on a tandem-wing design would present the same problems as canard flaps. Slotted flaps with chords of up to 40 per-
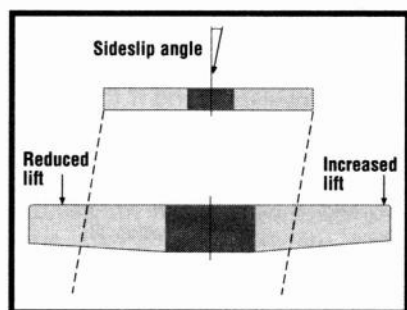
Figure 22.
The aymmetric canard downwash due to sideslip.

cent of the wing's chord may be used on foreplanes, as shown in Figures 20 and 21. Use of such wide-chord flaps on the aft plane is not recommended. Chapter 14, "Design for Flaps," provides insight into flap design, construction and actuation.

■ **Dihedral.** Foreplane downwash impacting asymmetrically on the aft wing in a side slip creates a powerful dihedral effect when the plane yaws (Figure 22). John Roncz's three-surface "Eagle" has no dihedral; its wings are "flat." Flight tests confirmed that dihedral was not required. The same would apply to canards and, to a lesser extent, to tandem-wing design

■ **Landing-gear design.** Chapter 16, "Landing-Gear Design" covers this subject. The stalling characteris-

tics of the foreplane govern landing-gear design, for all three versions.

■ **Structural design.** The discussion of stressed-skin design in Chapter 13 applies to all three types of front-wing-first airplanes. Use of this type of structure would simplify weight estimating and provide optimum weight-to-strength ratios.

GLIDER EXPERIMENT

At first glance, the "Plover" appears to be a tailless glider; in fact it's a canard. The forward-swept inner panels are the aft plane, and the unswept outer panels are the canard. The inner and outer panel aerodynamic centers are shown in Chapter 26, "Construction Designs," as are the area's airfoil sections' neutral point and CG locations.

First test glides, with a vertical surface of normal size, were a disaster and the treacherous behavior of swept-forward wings was forcibly revealed.

When yawed, the retreating panels' centers of drag and lift move outboard. The advancing panel's centers move inboard. The drag imbalance greatly exaggerates the yaw, and the lift imbalance causes a violent roll in the opposite direction. After a couple of damaging crashes and some pondering, the vertical surface was enlarged by 300 percent of its original area. The model then flew well.

The forward panels were readily damaged on landing. After a summer of repeated flying and repairing, it was put to one side. The basic concept has merit; it avoids the impact of foreplane downwash on the aft plane. A powered version would be an interesting design challenge. ▲
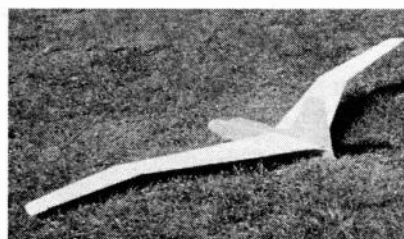
The Plover glider canard.

Chapter 23
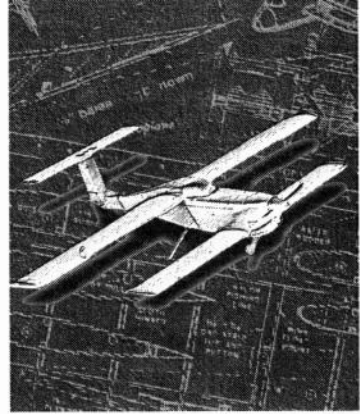
Tailless Airplane Design

The flying wing has intrigued designers since the early days of flight. Its structural simplicity, graceful flight and low weight and drag potential have major appeal. Despite this, no full-scale, tailless airplane or flying wing has ever been produced in quantities that could rival those of conventional aircraft. This chapter explores the pros and cons of tailless design.

CENTER OF GRAVITY LOCATION

For longitudinal stability, the CG of any type of airplane must be ahead of its neutral point (NP). On a conventional (with tail) airplane, the horizontal tail's area and its distance from the wing (both horizontally and vertically) determine the NP location. It is possible to have the CG ahead of the wing's aerodynamic center (which lies at 25 percent of the wing's MAC) or behind it and still maintain an adequate static (stability) margin between the CG and the NP behind it (see Chapter 7, "Horizontal Tail Design").

On a tailless aircraft, the wing's aerodynamic center (AC) and the NP coincide. For longitudinal stability, the CG must be ahead of the AC/NP location. This results in a nose-down imbalance. For equilibrium, the wing must provide a balancing force as shown in Figures 1A, 1B and 1C.

For a conventional airplane, this balance is achieved by the horizontal tail, which is at some distance behind the CG to provide a long moment arm, so that a relatively small tail area does the job.

For a tailless aircraft, the wing itself must provide this balancing force. On a straight wing (Figure 1A), the moment arm is short, so a larger balancing force is required to produce the moment needed. To increase the length of the moment arm, designers have resorted to using wide chords, forward and backward sweep and delta wings (an extreme example of sweepback).

■ For plain *sweptback and delta wings,* the balancing force acts downward, *reducing* the wing's lift and requiring additional wing area to compensate (Figures 1A and 1B).

■ For a *forward-swept wing,* the balancing force acts upward, *increasing* the wing's lift. This allows less wing area and higher wing loadings (Figure 1C).

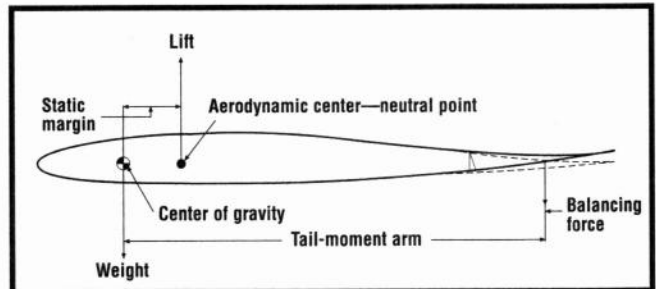Owing to the high balancing forces needed, a tailless airplane is especially sensitive to CG location.

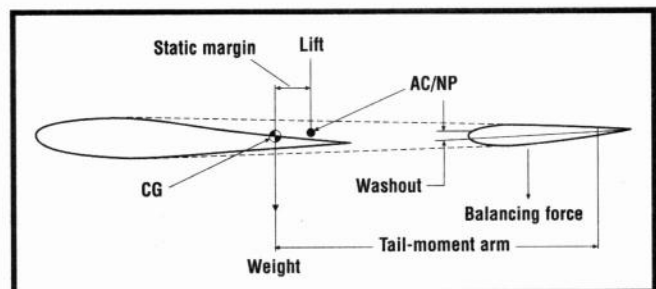Figure 1A.
Plain tailless force diagram; Eppler 184 airfoil.

Figure 1B.
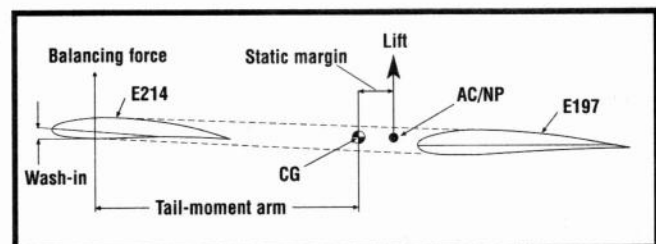*Sweptback tailless force diagram; Eppler 168 airfoil.*

Figure 1C.
Swept-forward tailless force diagram.

AIRFOIL CHARACTERISTICS

With their limited tail-moment arms, tailless airplanes—with the exception of forward-swept versions—can't tolerate airfoils that produce high nose-down pitching moments; such airfoils include those that have heavily cambered mean lines.

See the lift, drag and pitching moments for cambered airfoils E197 and E214 in the appendix. Such airfoils, when used on a tailless airplane, call for a substantially greater balancing force. Some early,

full-scale, tailless designs that employed cambered airfoils had sweepback and inverted, washed-out airfoil sections toward the wingtips. This provided the balancing force, but certainly did not improve the wing's lift.

To reduce or eliminate the airfoil's nose-down pitching moment, symmetrical airfoils or airfoils with reflexed mean lines were used. In the appendix, E184 and E230 are two reflexed airfoils; E184 has a low nose-down pitching moment, and E230 has a nose-up moment. An E184 airfoil placed inboard with an E230 airfoil placed outboard on a swept-back wing could provide sufficient balancing force. E168 is a symmetrical airfoil that has no pitching moment, except at the stall during which the airfoil becomes nose-down and is stabilizing.

Reflexed and symmetrical airfoils have substantially reduced max lift coeffients; E214 has a C_L max of 1.25, whereas E230 has a C_L max of only 0.78. Since both stall and landing speeds are directly related to the airfoil's C_L max, these reduced values result in substantially higher landing speeds or they necessitate an increase in wing area (lower wing loadings) to achieve those lower speeds.

The Plover

Several years ago, this author developed a swept-forward tailless glider called the Plover. The parallels between it and canard design are evident. The straight outer panels equate to a canard's foreplane, and the swept-forward inner panels are like the canard's aftplane. A vertical tail area close to 10 percent of the wing's area was required for directional stability.

This model was not particularly successful. In other than a wings-level landing, the outer panels were easily damaged and it was CG-sensitive, but it proved the validity of canard technology.

HIGH-LIFT DEVICES
The lift that a wing generates is equal to the square of its flying speed. Assuming a constant AoA, doubling the speed increases lift fourfold.

At high speed, it's obvious that less wing area is required (see Chapter 5, "Wing Design"). At high speeds, less wing area means reduced drag—both profile and induced—but substantially higher stall and landing speeds. The Gee Bee racers of the '30s reflected this philosophy, and they landed "hot."

To provide slower landing speeds with reduced wing area, the modern approach is to use high-lift (HL) devices (such as split, slotted, or Fowler flaps) on the wing's trailing edge (combined, in some cases, with leading-edge slots and flaps). Use of these devices results in very large increases in the wing's C_L max.

Under the conditions described above, the wing's area is determined by its HL-device-assisted C_L max and the landing speed desired. Unfortunately, when deployed, these high-lift devices produce heavy nose-down pitching moments that are beyond the capability of tailless aircraft (with the exception of forward-swept types). To overcome this, small split flaps, which produce more drag than lift, are sometimes used.

On conventional "tailed" airplanes, the increased nose-down pitching moment is compensated for by the heavy downwash angle increase provided by the deployed HL devices striking the tail, and by stabilizer/elevator action. Obviously, on a tailless airplane, the wing's downwash provides no such compensating force.

For tailless airplanes (except swept-forward configurations) all three factors—CG location, reduced airfoil C_L max and limited use of HL devices—require an increase in wing area compared with conventional aircraft, and this reduces the tailless craft's efficiency.

This author's Swift has 600 square inches of wing area and weighs 92 ounces (gross) for a wing loading of 22 ounces per square foot. Its airfoil is the E197, and it is equipped with slotted flaps whose chord is 30 percent of wing chord, and which occupy 60 percent of the wing's trailing edge. The C_L max (flaps extended 40 degrees) is 1.80; stall speed is 17mph.

For an aircraft with a wing C_L max of 0.90 to achieve the Swift's stall speed would require a wing loading of 11 ounces per square foot. Because of the lower loading, a substantial increase in wing area and weight would result. It is not improbable that this increase would equal the weight savings that would result from using a shorter fuselage and absence of a horizontal tail. Using the Swift's gross weight of 92 ounces, to achieve the 17mph stall, the wing area for a tailless model would be 1,200 square inches—a 100-percent increase. Top-speed performance would be adversely affected.

SWEPT-FORWARD TAILLESS AIRCRAFT
Of the tailless configurations, only the swept-forward (SF) has an upward lifting balancing force, which adds to the wing's overall lift, rather than the downward, lift-reducing balancing force of the other configurations.

Very few SF tailless aircraft—either full-scale or model—have been designed and built, owing to two major factors:

■ The SF wing has a strong tendency to twist under load, increasing its AoA. Unless the wing is torsionally very strong, this tendency leads to flutter and disastrous failure. A stiff, heavy structure is needed. Modern, composite, stressed-skin design has largely overcome this problem.

■ An SF wing is directionally unstable and requires large vertical surfaces for directional stability.

Since lift is all upward, the nose-down pitching moment of cambered airfoils is easily overcome with an SF wing. Such airfoils, with their higher C_L max, may be used.

High-lift devices, such as slotted flaps, may be incorporated at the inboard trailing edges. Elevators are depressed at the wingtips to increase lift forward of the CG and offset both the added lift and the nose-down pitch of the extended HL devices that are behind the CG. In this condition, both elevators and flaps add to the wing's total lift.

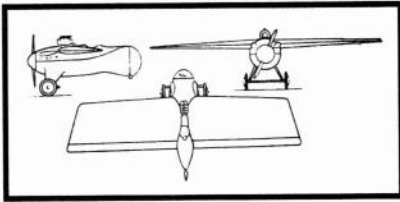An SF wing characteristically stalls at the wing root first. Because

Figure 2.
The 1922 Arnoux "Simplex" racing mono-plane designed by Carmier.

this area is aft of the CG, such a stall causes the airplane to nose-up. To permit the SF wing to stall ahead of the CG *first* (causing nose-down), an increase in the wing's angle of attack toward the tip (wash-in) is desirable. This adds to the wing's twisting tendency and reinforces the need for torsional strength.

It does not require much imagination to see a parallel between this SF wing and a canard configuration:

■ In both, lift is upward.

■ The canard foreplane and the SF wing's outboard areas must both stall first.

■ The aft wing of a canard and the inboard portions of a SF wing must arrive at their angles of zero lift before that of the foreplane or outboard panel.

Canard design technology is thus applicable to SF tailless design, with one major difference: the inner portions of the SF wing are not affected by downwash from the outer portions. In canard design, downwash from the fore-plane significantly affects the aft-plane and is a design consideration.
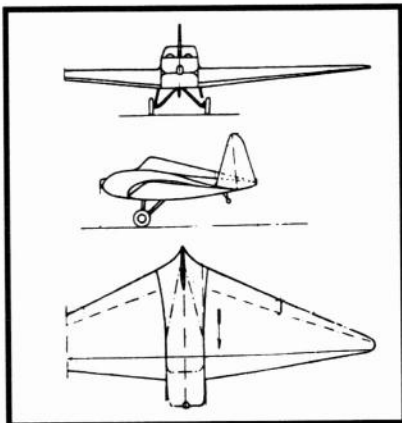
Figure 3.
The 1935 Fauvel A.V. 10 tailless light airplane.

PLAIN TAILLESS AIRCRAFT

Figure 2 is a three-view drawing of the Arnoux "Simplex"—a 1922 racing monoplane, which was powered by a 320hp Hispano-Suiza engine. Its top speed was 236mph and its landing speed a brisk 84mph. It crashed during a test flight before the Coupe Deutsch.

Flight controls were elevons and rudder, and the airfoil was a symmetrical Goettingen 411. The very short tail-moment arm from the CG to the elevons must have made longitudinal control and CG location very sensitive; stops restricted the downward movement of the elevons. Roll and yaw control was satisfactory, and the structure was
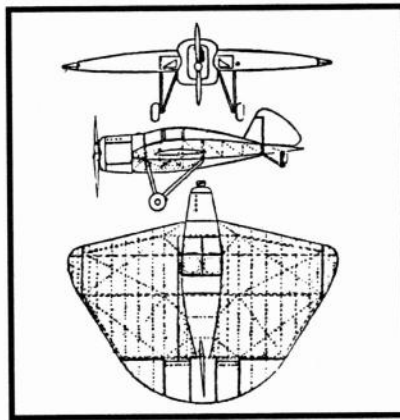

Figure 4.
Hoffman disk-type airpane.

good. To obtain the correct CG, a tractor engine and propeller were the only choices. The major disadvantage, longitudinally, of the plain wing is the short tail-moment arm.

Obviously, lower aspect ratios with the resulting longer chords would be an improvement. Coupling low AR with heavy taper results in even longer central moment arms.

Figure 3 illustrates the concept—the Fauvel A.V. 10 of 1935. Powered by a 75hp Pobjoy engine, it had a sharply tapered wing with an AR of 5.4. Its airfoil was heavily reflexed, without washout, and uniform across the span. Inboard trailing-edge elevators provided pitch control; outboard ailerons provided roll control; and a rudder controlled yaw.

The AV 10 performed well and was granted a French certificate of airworthiness, but no further developments occurred. Structurally, the

wide, thick wing was light. A trac-tor engine and prop were the only choices.

The low-AR, wide-chord configuration was developed into the Hoffman disk-type airplane shown in Figure 4. The airfoil was a stable, reflexed M-section; the ailerons were the wingtip, floating variety; the elevators were inset at the semi-circular trailing edge, and a large vertical surface was provided. An 85hp tractor engine and prop were used. It flew well, but no further developments took place.

Low-AR wings do not stall until they reach high angles of attack; and the danger of spins is remote. Slow, safe, landings at high angles of attack are possible. The Hoffman's long main landing gear reflects this capability.

In R/C model terms, the tailless plain wing concept is alive and well in Bill Evans' "Scimitar" series.

SWEPTBACK AIRCRAFT

Sweepback (SB) favors higher aspect ratios. For a given angle of SB (measured on the ¼ chord line) higher ARs result in longer tail moment arms for better longitudinal control. Higher SB angles have the same effect but result in lower lift.

High ARs demand greater strength and higher weight. Also, sweepback induces twist under flight loads, and that tends to reduce the wingtip's angle of attack. Good, torsional stiffness is required to remedy this.

During the '30s, the German Horten brothers developed a series of flying wings as shown in Figures
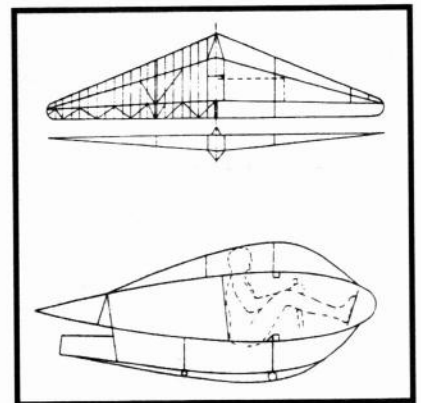

Figure 5.
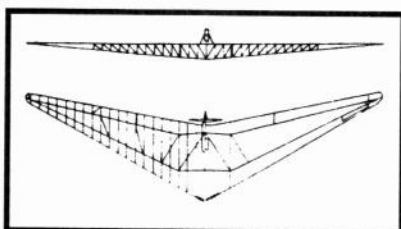*The Horten brothers' first "flying wing" sailplane of 1933.*

Figure 6.
A 60hp pusher prop on a Horten glider.

5 and 6.

The Horten flying wings had:

■ Thick, sharply tapered planforms of symmetrical airfoil sections.

■ Washout toward the wingtips.

■ Elevators inboard and ailerons outboard on the trailing edges.

■ Yaw control was provided by air brakes placed outboard on both the top and bottom surfaces, flush with those surfaces when not being used. No vertical surfaces were used.

■ Dihedral on the lower wing surface.

■ A cabin arrangement that, in later models, required that the pilot lie in a prone position, completely enclosed in the wing.

One version had an enclosed 60hp engine driving a pusher prop on an extension shaft (Figure 6). For R/C models, an electric motor enclosed in the wing, with an extension shaft, driving a pusher prop at the wing's trailing edge would be practical.

Figure 7 illustrates the Buxton glider of 1938. This interesting design had a thin, high-AR wing, symmetrical airfoils washed out to the wingtips, and vertical fins and rudders at the wingtips. Outboard elevons provided pitch and roll control. The pilot was housed in a pod below the wing. Small split flaps were used at the wing roots.
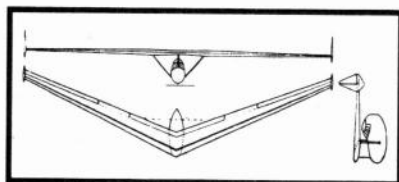

Figure 7.
The Buxton glider of 1938.

A more recent flying-wing design, the Davis Wing, is shown in Figure 8. It incorporates the design features of the ill-fated Northrop flying-wing bombers of the '40s. It also bears a close resemblance to the Horten designs.

The engine is a 65hp, water-cooled Rotax 532, in a well-stream-lined pusher installation.

This wing had an AR of 6.67, a surprisingly large wing area of 240 square feet and a gross weight of 975 pounds for a wing loading of 4.06 pounds per square foot (low for a powered full-scale light airplane). A Cessna 172 weighs 2,300 pounds, has 174 square feet of wing area and wing loading of 13.2 pounds per square foot.

The Davis's top speed was a brisk 150mph—excellent, on 65hp; stall speed was a modest 42mph, thanks to its low wing loading. Its empty weight was 565 pounds, so it carried 73 percent of its weight as useful load.

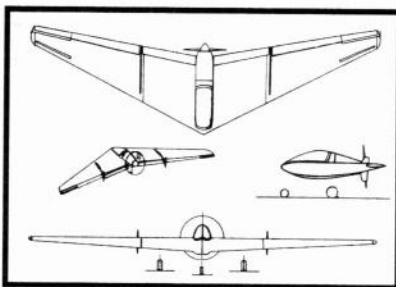The wing is sharply tapered and swept back 28 degrees on the ¼

Figure 8.
The Davis Wing.

chord line. Controls consist of split-drag rudders outboard and elevons inboard. Wisely, the narrow tips are equipped with fixed leading-edge slots to delay wingtip stalling. Obviously, the pusher engine and prop are best. No dihedral is needed on sweptback wings.

Richard Engel's "Winglet" (*Model Airplane News,* March 1994), powered by a pusher .40 and with a wing area of 900 square inches, is a good example of a flying-wing design.

COMBINED PLAIN AND SWEPTBACK AIRCRAFT
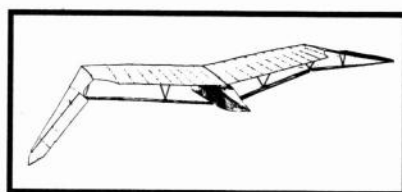Figures 9 and 10 show the 1921 Wenk-Peschkes "Weltensegler" sail-

Figure 9.
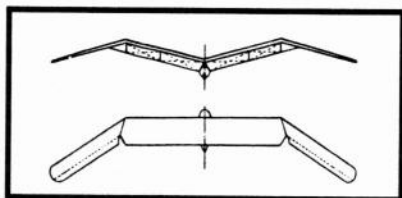*The Wenk-Peshkes "Weltensegler" sailplane at the 1921 Rhön Competition.*

Figure 10.
Wenk-Peschkes "Weltensegler" sailplane (1921 type).

plane. This design illustrates the combined plain and sweptback wing planform, with a rectangular, dihedralled center section and anhedralled, sweptback, outer panels. The outer panels are set at lower angles of attack to provide the download to balance the forward CG. Controls were on the trailing edge of the outer panels.

These outer panels, like an inverted V-tail, provided both horizontal and vertical surfaces. The elevons acted, in concert, as elevators; but differentially as ailerons. The downswept controls also acted as rudders into the elevon-induced turn, thus overcoming any adverse yaw.

As Figures 9 and 10 illustrate, the wing was externally braced, it had an AR of 11, and it weighed a low 93 pounds for a span of 53 feet and an area of 195 square feet. It flew successfully, but later broke up in flight, causing the pilot's death.
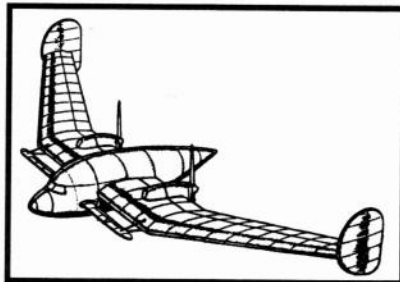
Figure 11 portrays a British pro-

Figure 11.
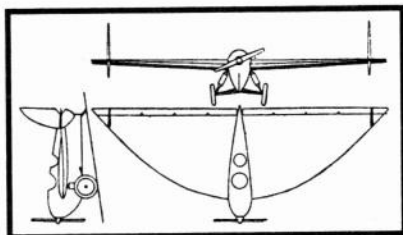*Tailless airplane of F. Hadley Page and G.V. Lachmann.*

Figure 12.
The Tscheranowsky-Gruhon "Parabola."

ject: the Handley Page-Lachmann twin-pusher-engine tailless. This craft had the combined plain and swept planform, but with large vertical surfaces at the wingtips. This compensated for the fuselage and countered an "engine-out" situation.

The tab on the floating airfoil in front of the main plane is coupled with the landing flaps to counteract the nose heaviness caused by the deflected landing flaps. The advent of WW II probably stopped further development of this interesting design.

DELTA WINGS

The delta planform has the advantage of flying to very high angles of attack before stalling. High-lift devices are neither practical nor needed on this type of wing.

Over the years, many delta-wing designs have evolved. Figures 12 and 13 illustrate two such planes. Figure 12 is of the Tscheranowsky-Gruhon "Parabola," which was built by the Z.A.H.I. in 1931. Its wing section had a thickness of 7.7 percent. Figure 13 shows a design that might raise problems with lateral stability–the 1930 Abrial A-Viii light airplane. It was powered by a 95hp engine; it had a 22.4-foot span and 173 square feet of wing area; and it weighed 1,320 pounds. Note the reflexed airfoil.
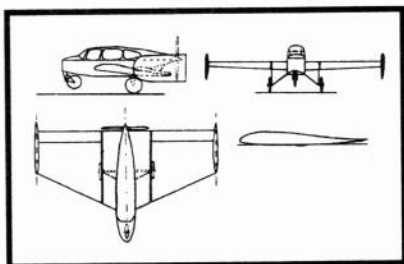

Figure 13.
The 1930 Abrial A-Viii light delta-wing airplane.

Figure 14 illustrates the original configuration of a Delta RPV (remotely piloted vehicle), which underwent wind-tunnel and flight tests at the Langley Research Center in Virginia.

Figure 15 shows the modifications resulting from wind-tunnel tests, confirmed by subsequent flight tests. Note the NASA leading-edge droop (*Model Airplane News*, June 1990—NASA Safewing) and RAO slots on the outboard wing panels to improve stall resistance. An R/C model based on the modified design would be an interesting project. The low AR, wide chord, and thick airfoil result in a light, strong structure. Obviously, a
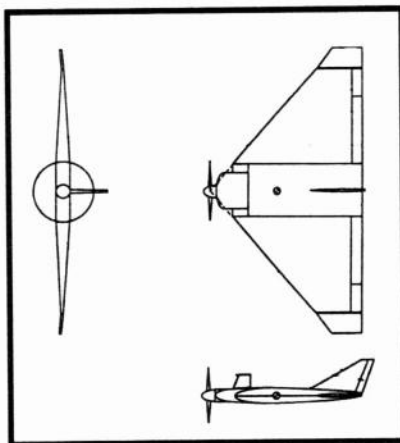

Figure 14.
Delta RPV; three-view sketch of base-line configuration.

tractor power unit is required; a pusher installation would present serious problems in correctly positioning the CG.

SWEPT-FORWARD WINGS

Few swept-forward tailless airplanes have been developed. Figure 16 shows one such design—the Landwerlin-Berreur racing monoplane of 1922. This "Buzzard"-type aircraft featured separate elevators and ailerons and a low-aspect-ratio tail fin. It was powered by a 700hp engine.

Figure 17 (from an *Aeromodeler* annual)

shows a swept-forward, tailless, free-flight model. Note the heavily cambered airfoil sections and the large vertical surface.

AILERONS AND ELEVONS

Adverse yaw is an important consideration when dealing with high-aspect-ratio (AR) wings of plain, swept-back or swept-forward configurations—particularly for ailerons or elevons located near or at the wingtips. On this author's designs, the modified frise aileron (see Figure 1A in Chapter 10, "Roll Control Design") with heavy differential has been proven to provide roll control without adverse yaw. However, if they're used as elevons for elevator control, they should have equal up and down action. A two-servo arrangement, where the elevator servo moves the aileron servo back and forth, will provide the elevons with equal up and down action as elevators, and with differential action as ailerons.

On plain or delta wings of low AR, the need for anti-yaw differential is greatly reduced. On swept-forward wings (without high-lift devices), modified frise ailerons located at the wingtips and with anti-yaw differential are suggested. Elevators are then located at the inboard trailing edges where their moment arm from the CG is the greatest.
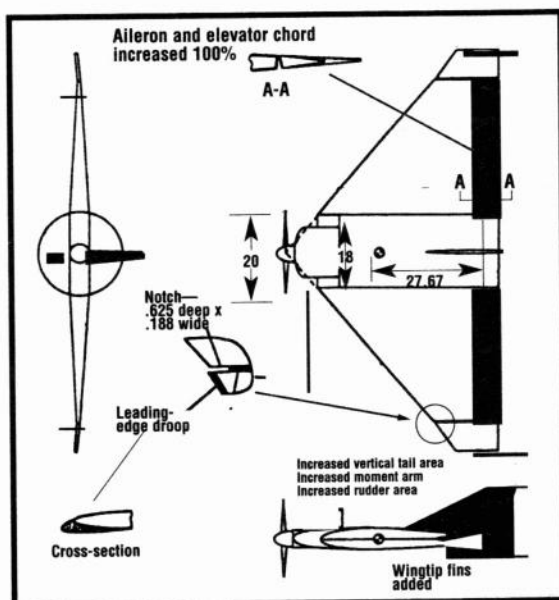
For swept-forward wings with

Figure 15.
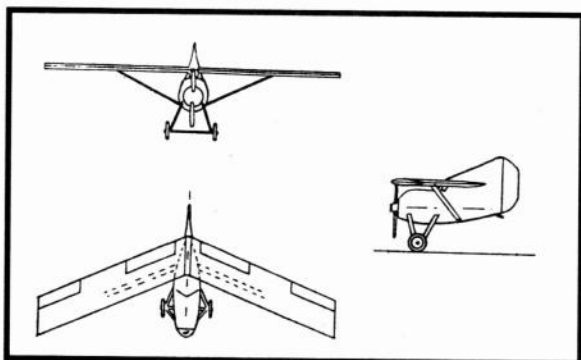*Delta RPV configuration modifications.*

Figure 16.
1922 Landwerlin-Berreur.

inboard, high-lift devices, slotted elevators/elevons (similar to the slotted flap shown in Chapter 14, "Design for Flaps") are suggested. These provide additional lift to balance that of the high-lift devices.

It's suggested that elevators that are separate from ailerons be used where possible. The top-hinged variety (see Figure 1C in Chapter 10) with equal up/down action is suggested.

VERTICAL SURFACES

For plain, delta and swept-forward tailless planforms, a single vertical surface on the centerline is optimum. Placing the rudder-hinge line at or behind the wing trailing edge provides a healthy moment arm. Positioning ¼ to ⅓ of the vertical tail area below the wing will improve its effectiveness at wing-high angles of attack where the above-wing portion may be blanketed by the wing's turbulence. The anhe-draled and sweptback outer panels of the combined plain and sweptback tailless configuration present side areas that act as vertical surfaces. (The verti-

cal tail area is described in Chap-ter 9, "Vertical Tail Design and Spiral Stability.")

Note that the sideways-projected areas are proportional to the angle at which these outer panels are anhe-draled; and their plan-view area is inversely proportional to this angle.

On sweptback tailless wings, the location that provides the greatest vertical tail-moment arm is at the wingtips (control surfaces with greater moment arms need less area for equal effectiveness). If symmetrical airfoil sections are used in the dual-wingtip vertical surfaces, "toeing-in" their chord lines by 2 or 3 degrees is suggested.

Two forms of winglets—the Whitcomb and the Grantz—may be used as wingtip vertical surfaces (see Figures 18 and 19). The dimensions of both are related to the wingtip chord and will provide vertical areas that may or may not be adequate. Determine the areas needed and, maintaining the same proportions, size the winglets to the desired area. Rudder area should be 30 percent of the area of any of the vertical surfaces dis-

cussed. On swept-forward wings, because of the directional instability of this planform, large central vertical surfaces are mandatory.

This author's Plover glider (see Chapter 26, "Construction Designs") had a vertical tail-moment arm of twice the wing's MAC and an area 10 percent of the wing's. A large vertical surface could result in spiral instability

SPLIT-DRAG RUDDERS AND SPOILERS

Northrop and Davis flying wings employed split-drag rudders at the wingtips as in Figure 20. Opened on one wing panel, the added drag acted like rudders. Engel's "Winglet" also has split-drag rudders.

Spoilers may be used for both glide control and directional control, but they may also replace ailerons for roll control when used on the wing's upper
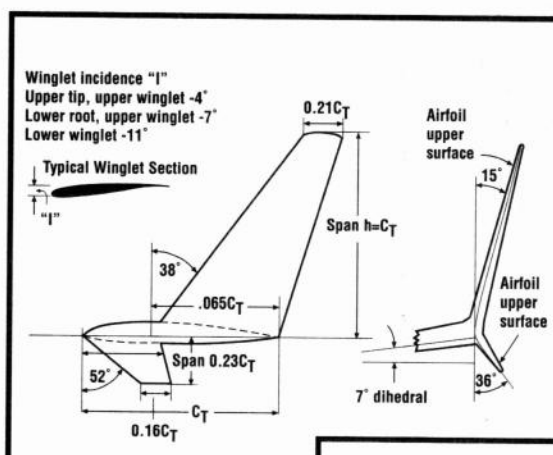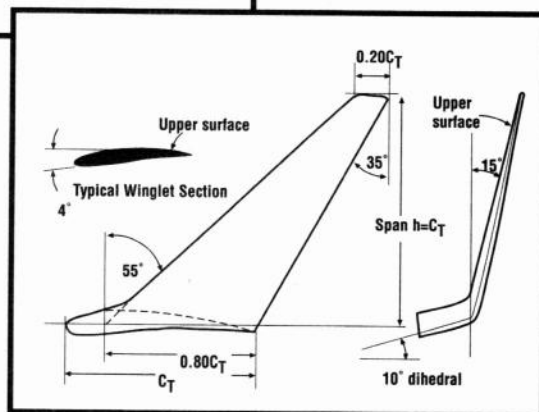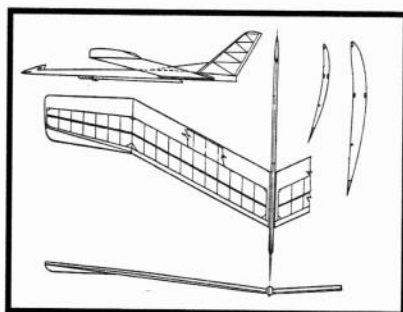

Figure 18.
Whitcomb Winglet

Figure 19.
Grantz Winglet.

Figure 17.
M-tailless (with negative sweepback)
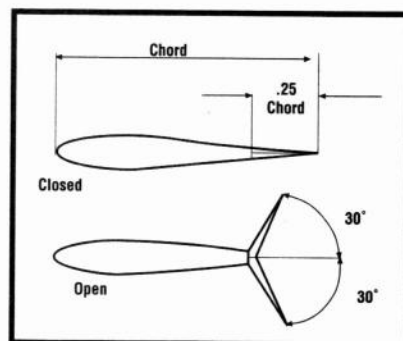*by K. Ginaiski of Poland.*

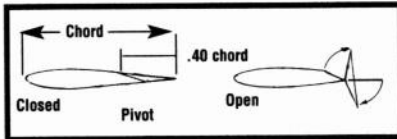*Figure 20.*
Split-drag rudder design.

Figure 21.
Spoil-flap design.

surface only.

Placing the spoiler's LE beyond 70 percent of the wing chord avoids the lag between control action and response, which is characteristic of spoilers located farther forward on the wing chord.

Spoilers create desirable into-the-turn yaw, because only the spoiler on the inside of the turn is raised; its mate remains flush with the wing.

The Hortens used spoilers on both upper and lower wingtip surfaces for directional control. When not in use, both split-drag rudders and spoilers lie flush with the wing surface and cause no drag.

SPOIL FLAPS

Spoil flaps are shown in Figure 21. They were used on this author's "Dove"—a powered glider. The spoil flaps were used for glide control and proved to be successful. Their combined areas were 7 percent of the Dove's wing area. Extended, they didn't change the Dove's in-flight attitude, but they did cause a greater sink rate. They were used for slow, steep descents from height and for short, no-float landings. Used separately, they could act as drag rudders.
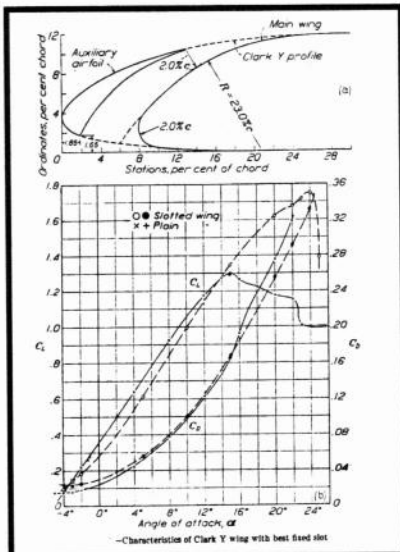
LEADING-EDGE FIXED SLOTS

Despite washout, swept-back, highly tapered wings are prone to tip-stalling at high angles of attack. This results in loss of longitudinal control. Fixed LE slots, as shown in Figure 22, delay the stall about 9 degrees and increase the max C_L substantially, but have very low drag. Both Northrop and Davis used them at the wingtips, extending for 25 percent of the wing's semi-span.

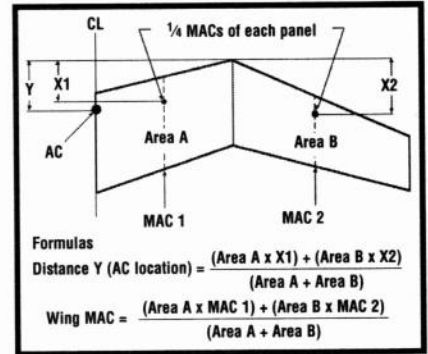The basic dimensions for the slot shown in Figure 22 may be applied to any airfoil section.

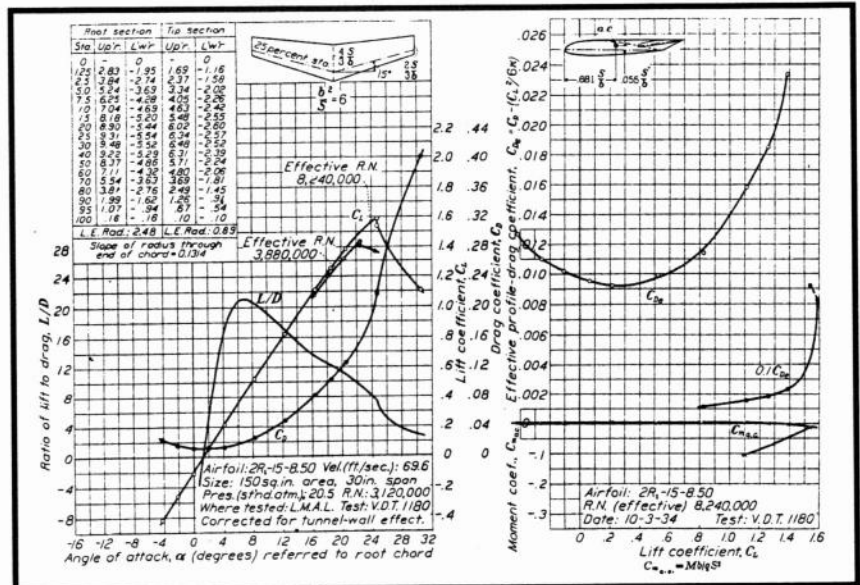**Figure 23.**
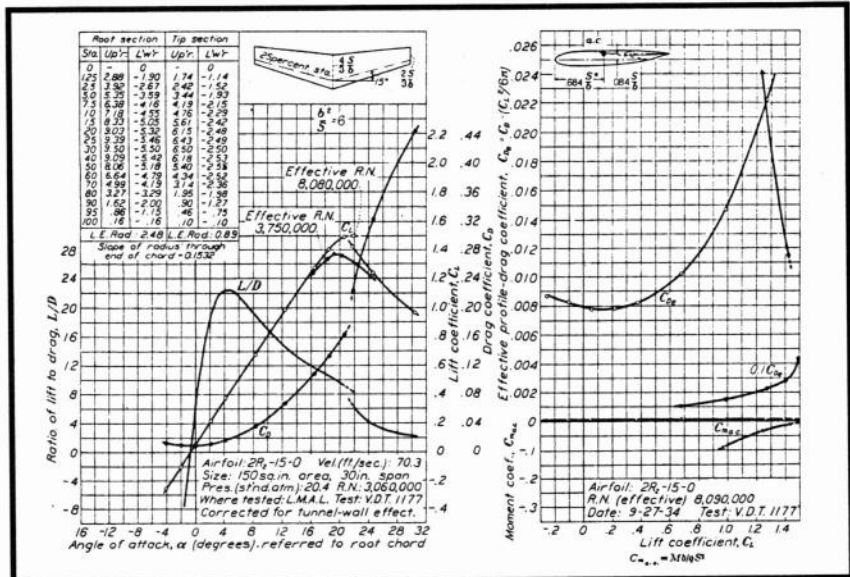*AC and MAC of multi-tapered wings.*

Figure 23.
Tapered NACA $2R_1$—15—8.50 airfoil.

Figure 22.
Fixed leading-edge slot at Rn 600,000.

Figure 24.
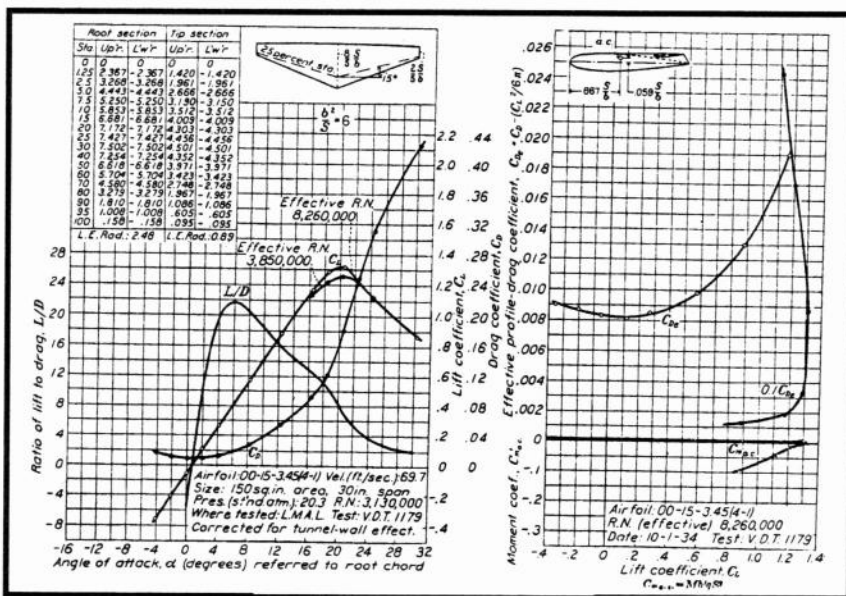*Tapered NACA $2R_1$—15—0 airfoil.*

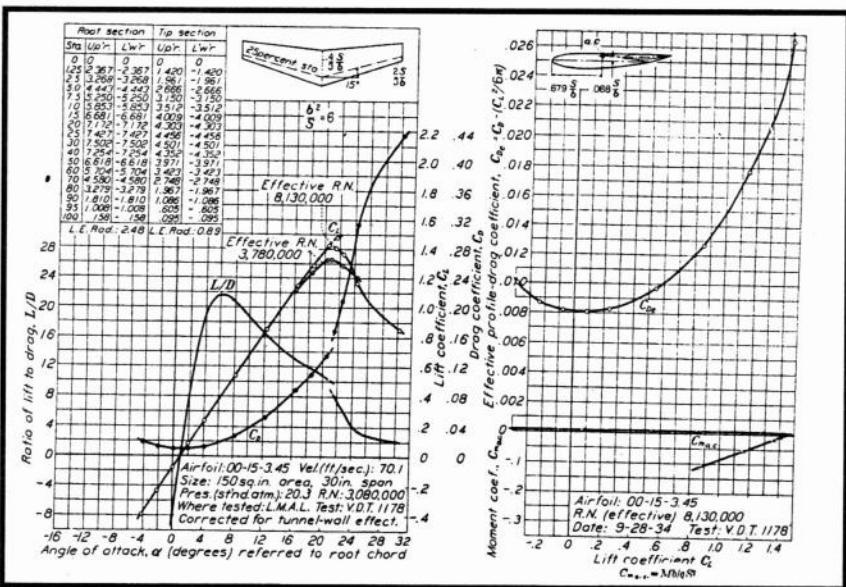Figure 26. Tapered NACA 00—15—3.45 (4 to 1) airfoil

Figure 27. Tapered NACA 00—15—3.45 airfoil

WASHOUT AND SWEEPBACK

Figures 24, 25, 26 and 27 reflect wind-tunnel tests performed by NACA on four different wings. All were stable at the stall (pitching moment becomes negative). The wing shown in Figure 24 has a reflexed airfoil and 8.5 degrees of washout. The wing in Figure 25 also has a reflexed airfoil but no washout. The wings shown in Figures 26 and 27 have 3.45 degrees of washout.

In Figures 24, 25 and 27, the taper ratios are 2 to 1 from root to tip. In Figure 26, the wing's 4-to-1 taper invited early tip-stall, along with reduced C_L max. These figures

provide root and tip airfoil ordinates and aerodynamic center location. "S" is wing area and "b" is span. Although tested at high Rns, these wings are a useful guide for swept-back designs.

DIHEDRAL

Sweptback and delta wings need no dihedral. The plain and swept-forward types should have the dihedral angles that are suggested in Chapter 9. Combined plain and sweptback wings need a healthy amount of dihedral in the plain section to compensate for the anhedraled tips.

STATIC MARGIN

As previously discussed, the AC and NP of tailless airplanes coincide. For stability, the CG must be ahead of the AC/NP. This produces a "force couple"—lift upward and CG downward—that must be balanced by a rear download.

The larger the static margin (the distance between the CG and AC/NP), the greater the aft download necessary. Centrifugal force created during maneuvers requires an increase in all three: lift, weight at the CG and balancing force.

Large static margins, however, are more stable longitudinally; small margins promote maneuverability, but reduce stability. A safety margin (SM) of 5 to 10 percent of the wing's MAC is suggested.

The swept-forward wing obtains equilibrium by increased lift created toward its tips. This permits the use of cambered, high-C_L-max airfoils, healthy stability margins and high-lift devices.

WEIGHT DISTRIBUTION

This is important, longitudinally, for tailless airplanes, because of their limited longitudinal control when compared with "tailed" airplanes (Chapter 11, "Weight Distribution in Design"). Massing the fixed weights of power and control units as close to the CG as possible is recommended for tailless designs. Positioning the fuel tank on the model's CG will avoid a possibly destabilizing shift of the CG as fuel is consumed and the tank becomes lighter.

LOCATING THE AC AND MAC

In Chapter 1, "Airfoil Selection," graphic methods for locating the AC and MAC of straight, tapered and sweptback wings are explained.

For multi-tapered wings—such as the one shown in Figure 23—obtain the ¼ MACs of each panel (A and B) using the methods shown in the aforementioned article. Calculate the area of each panel (in square inches) and, using the simple formulas that accompany Figure 23, obtain the wing's AC and its MAC. ▲

Chapter 24
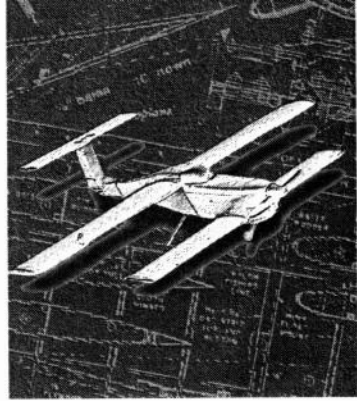
Hull and Float Design

Few events give greater satisfaction than the successful first flight of a model airplane that one has conceived, designed and built. Ensuring the success of that first flight and of subsequent flights is what this series is all about.

Flying off water adds two new elements: hydrostatics (buoyancy) and hydrodynamics (planing lift).

Flying boat or floatplane flying is, if anything, more fun than flying off land. There are few trees over water to reach up and grab your model, and water is more forgiving than terra firma.

■ **Float and hull basics.** Figure 1 shows views of a float, or hull, with three cross-sections. Note the following key points:
—The "step" separates the forebody from the afterbody.
—The "keel flat" is the reference line for the "trim angle" shown in Figure 2.
—The "sternpost angle" governs the hull's (or float's) trim angle at the "hump."
—The "beam" is a critical dimension.
—The "step depth" is also a critical dimension.
—The "angle of deadrise" bears on the hull's planing performance.
—The "deck" is only a reference line. The top contour is the designer's choice.

■ **Float and hull factors.** For successful water flying, the following conditions must be met:

—There must be adequate buoyancy with substantial reserve while afloat.
—Planing surfaces should have a wetted area that's large enough to permit the model to accelerate to flying speed quickly.
—The hull's (or float's) trim angle at the hump should not cause the wing's airfoil to exceed its stalling angle of attack.
—Spray should be well-controlled; in particular, it should be prevented from hitting the propeller.
—There should be no porpoising on takeoff, and no skipping on landing.
—The model should weathercock to face into the wind when at rest, or when taxiing on water at low speeds.

PLANING ACTION AND THE STEP

Figure 2 illustrates the step's function. Planing at speed, the forebody creates a trough in which the afterbody planes. With adequate step depth, the hull or float rides on two areas, and porpoising, or skipping, is minimized.

HULL DEVELOPMENT

The hull or floats described here were developed by NACA scientists and tested in 2,000-foot-long towing basins. Recorded were:

■ Water resistance, with a range of loads.

■ Trim angles, "free to trim" under hydrodynamic forces in the displacement range, i.e., up to the hump and at various controlled trim angles at planing speeds in excess of hump speed.

■ Scale-wing lift forces were included in the tests.

■ Spray, porpoising and skipping tests were conducted during simulated takeoffs and landings.

■ Optimum CG locations, relative to the step.

Two hull or float designs were selected for this chapter. The
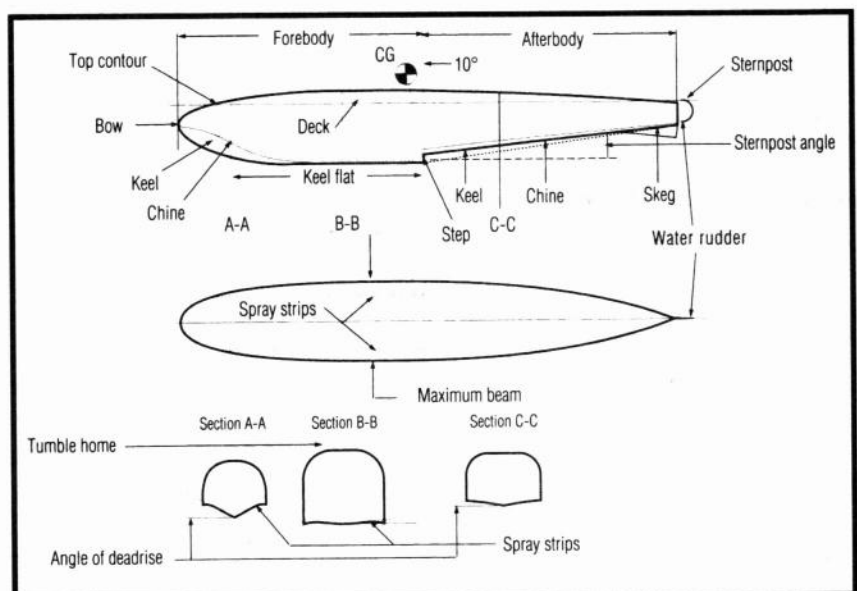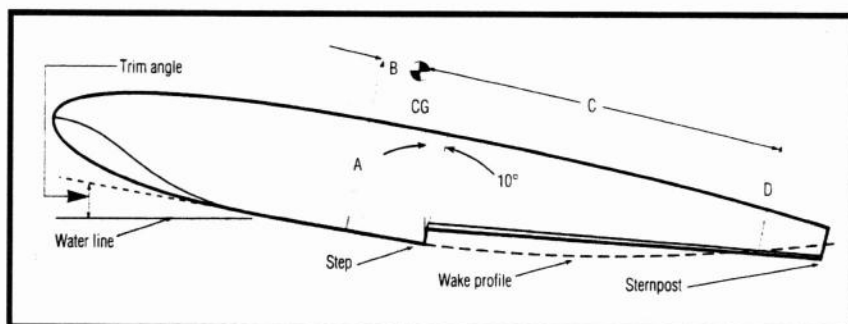
Figure 1.
Hull or float basics.

Figure 2.
Forces on a hull in two-step planing.

dimensions of both are comparable to those of R/C model water planes.

The first design has a short afterbody that's suitable for floatplanes. The second, with a long afterbody, is suitable for flying boats. Both designs were tested with sternpost angles of 6 , 8 and 10 degrees.

THE "HUMP"
Figures 3 and 4 provide resistance and trim angles for the short and long afterbody hull/floats. Both figures merit close scrutiny.

Note the high points in the resistance curves—known, for obvious reasons, as the "hump." Not surprisingly, the maximum trim angles coincide with the hump. Beyond hump speed, trim and resistance fall off as the hull accelerates to plane "on the step."

Up to the hump, trim is controlled by both hydrostatic and hydrodynamic forces with little effective elevator action. Beyond the hump, trim is progressively elevator-controlled as speed increases to liftoff velocity. Notable is the influence that sternpost angles have on trim angles *at the hump* for both afterbody lengths. By judicious selec-

tion of the sternpost angle, one can control hump trim angles within a fairly wide range.

There are two causes of hump resistance:

■ The hull is transitioning from being a floating object supported by hydrostatic buoyancy to being a planing object supported by hydrodynamic forces that act mainly on the forebody bottom, but with buoyancy still having some effect.

■ The hull/float must rise from full displacement depth, floating, to its planing depth aided by wing lift as it accelerates.

If the wing's AoA is above its stalling angle at hump trim, the wing will stall, and its contribution to raising the aircraft will be largely lost. Stalled, the wing will lose roll damping and aileron control, and the wing floats may dig in and cause water looping.

A model wing's stall angle—at low Rn, in ground effect, and with slotted flaps extended—may be as low as 10 degrees. A short afterbody hull/float with a sternpost angle of 10

degrees has hump trim of 12.5 degrees—well above the wing's stalling angle.

A properly designed forebody bottom and spray strips will run very cleanly. Spray hitting the wings, tail, or propeller can slow takeoff, not to mention damage the prop. At prop-tip speeds of close to 300mph, water is pretty "solid."

BEAM AND CG LOCATION
The hull/float maximum width, or beam, is critical for good water performance. *Too much beam* adds weight and air drag and makes the model hydrodynamically ready to lift off *before* the wing provides adequate lift. Skipping and wing stall may result.

With *too little beam,* the model sits low in the water and has higher hump resistance and heavier spray. Takeoff runs are longer. Too much beam is better than too little.

A study of NACA reports on hull design indicated that a hull, planing at the wing's stall speed, should generate enough hydrodynamic lift to support the model's gross weight. Further, at this speed, the "wetted" length of the forebody bottom would roughly equal the beam. The wetted area would then be the beam multiplied by the beam (beam^2).

The stall speed of a model depends on two factors: the wing's C_L max and its wing loading in ounces per square foot of wing area.

Model airfoils have a broad average C_L max of 1.00, so wing loading is the major factor governing a model's stall speed. It was concluded that a planing area (beam^2) relationship to wing loading could be used for float/hull-beam determination.
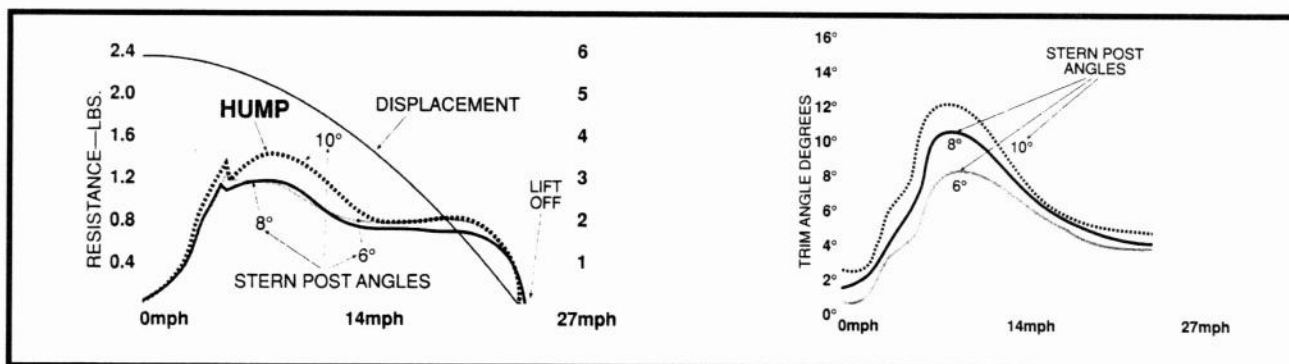

Figure 3.
Resistance and trim angles; short afterbody and sternpost angles of 6, 8 and 10 degrees; beam^2 loading at 2.5 oz. per square inch.
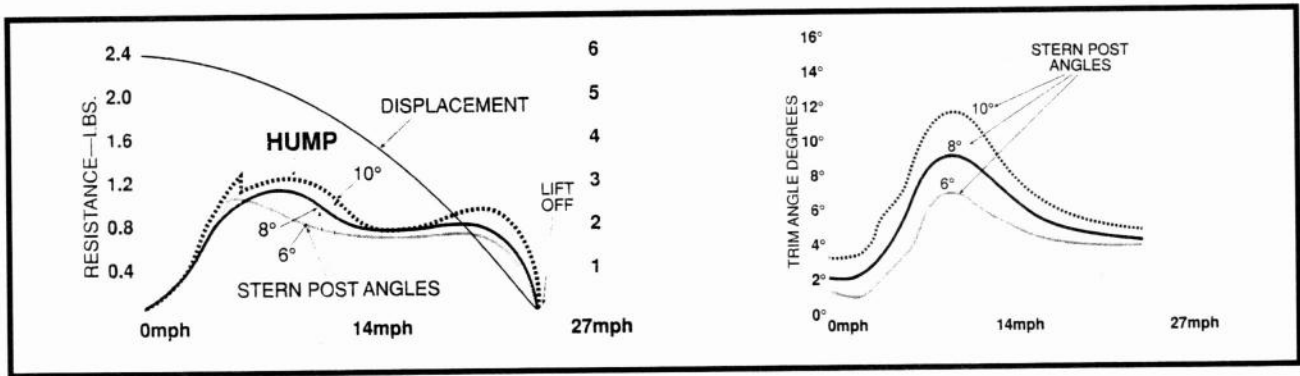
Figure 4.
Resistance and trim angles; long afterbody and sternpost angles of 6, 8 and 10 degrees; beam^2 loading at 2.5 oz. per sq. in.

An empirical solution to the beam problem was developed by an analysis of the wing loadings versus beam^2 loading of some 25 model flying boats and floatplanes, as shown in Figure 5.

The curve in Figure 5 averages the various points and may be used to determine your model's beam as follows:

■ Estimate your design's gross weight (Figure 6 will help).

■ Divide gross weight in ounces by the model's wing area in square feet to provide its wing loading in ounces per square foot.

■ Refer to Figure 5, and select the beam^2 loading that corresponds to the wing loading. For example, a wing loading of 20 ounces per square foot (horizontal) calls for a beam^2 loading of 2.6 ounces per square inch of beam (vertical).

■ Divide gross weight by the beam^2 loading. The result is the forebody's wetted area in square inches. A gross weight of 93.6 ounces, divided by a beam^2 loading of 2.6 ounces per square inch gives a wetted area of 36 square inches.

■ The beam is the square root of the wetted area. For 36 square inches, the beam would be the square root of 36, or 6 inches.

■ For a twin-float plane, divide the beam in half for each float, i.e., 6 divided by 2, or 3 inches per beam for each float. Step depth should be based on the total beam (6 inches, in this example) and would be 8.5

percent of 6 inches, or 0.5 inch for each float.

Figures 1 and 2 show the best CG location: along a line at 10 degrees to the vertical, ahead of the step/forebody bottom corner.

The wing's optimum location is with its center of lift (¼ of MAC) vertically in line with the CG.

PORPOISING AND SKIPPING
Porpoising is the up-and-down oscillation of the bow that occurs beyond hump speed. Skipping occurs on landing when the plane touches down several times. Landing too fast contributes to skipping, but adequate step depth (8 to 9 percent of the beam) avoids both of these undesirable characteristics.

PLANING TAIL HULLS
During the 1940s, in search of improved performance, NACA continued its towing-basin tests, but on a new hull form.

This hull featured a deep pointed step and a CG positioned at or behind the step. The aim was to have the afterbody contribute more to the hull's hydrodynamic lift—hence, the

name: "planing tail hull."

This author designed, built and flew a model with this hull—the Flamingo (see Chapter 26, "Construction Designs"). Powered by a Torpedo 0.15cid engine and controlled by a Babcock receiver and escapements, it flew well; the hull was efficient.

Some years later, it was modernized with an O.S. Max 0.35cid engine and a 4-channel radio that provided rudder, elevator aileron and engine control.

One very undesirable trait surfaced: the Flamingo always weathercocked pointing downwind—not good for takeoffs! This was because of its narrow afterbody, rearward CG and deep step, all of which combined to make the model's stern sink low in the water.
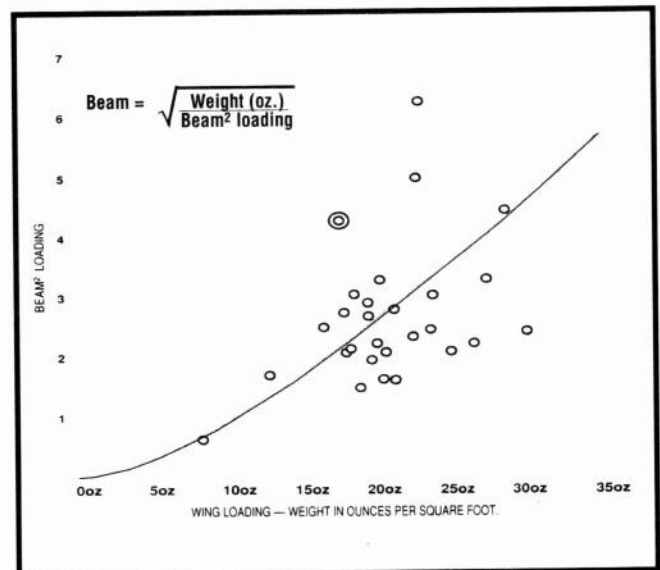

$$Beam = \sqrt{\frac{Weight\ (oz.)}{Beam^2\ loading}}$$

Figure 5.
Beam chart.

Above-water side areas were well forward; *below-water* side areas were well aft. Wind striking the side caused the model to weathervane—but pointing downwind. Water- and air-rudder control tried hard to correct this condition, but the downwind wingtip float's water drag rendered these controls ineffective.

NACA tested further variations of this hull and arrived at a configuration with no afterbody, just a very deep pointed step. Two booms extending back from twin engine nacelles replaced the afterbody and carried horizontal and twin vertical surfaces at their aft ends. This concept is reflected in the author's Sea Loon (Figure 7). It flew well.

But the booms, which also provided lateral stability on the water, did not sink into the forebody's wake as in Figure 2, but rode on or just under the undisturbed water on either side of the forebody, as in Figure 7.

Figures 3 and 4 do not apply to this configuration. Hump trim for the Sea Loon was established by carefully selecting the vertical-step depth to provide a 9-degree stern-post angle. The objective was to avoid wing stall at hump trim. Once past the hump, the twin booms were clear of the water.

FOREBODY
Figure 8 provides typical forebody cross-sections of full-scale water aircraft. Type A "flat" is the most effec-
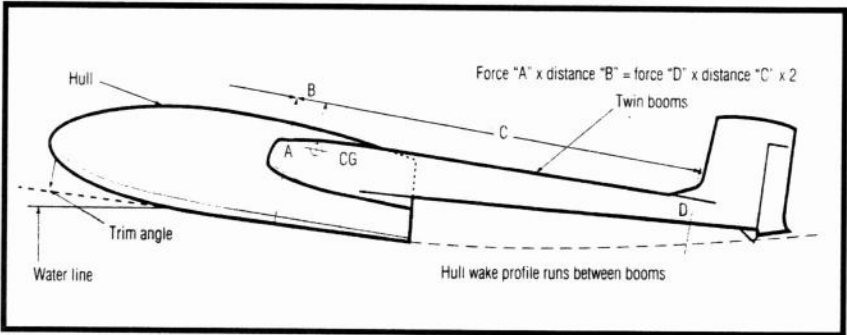

Figure 7.
Sea Loon II—planing action of hull and twin boom afterbodies.

tive hydrodynamically, but it planes with heavy spray. V-bottoms (type B) absorb landing shock, but reduce effectiveness and have heavy spray. Types C, D and E are designed to reduce "pounding" on takeoff and landing. Type F "cathedral" is popular for motorboats; spray is well-controlled without external spray strips, which are fragile and cause high air drag.

Type G "suggested" combines the efficiency of the flat bottom with the spray control of the flared and cathedral types. Above all, its construction is both simple and rugged (as shown in Figure 9) and applies to both hulls and floats.

Afterbodies do not require spray strips; otherwise, construction is the same as that shown in Figure 9 and based on the principles in Chapter 13, "Stressed Skin Design."

BOW CONTOURS
Bow contours for full-scale aircraft depend on the aircraft's function. Flying boats for heavy sea duty would have boat-like bows; for more moderate duty, bows may have a more streamlined shape. The type illustrated in Figure 10 has proven itself for model hulls and floats, and it's not difficult to make.

BUOYANCY
A cubic inch of water weighs 0.58 ounce. A model weighing 100 ounces would require a displacement of 100 divided by 0.58, or 173 cubic inches, *plus* 100 percent reserve buoyancy, for a total of 346 cubic inches.

The NACA models on which Figure 10 was based were designed with 100 percent reserves for a 94-ounce model (at the hull's lowest load). Adequate buoyancy is not a problem.

For twin floats, a maximum depth that's equal to the maximum beam and a length that's 60 to 70 percent of the airplane's length provide adequate buoyancy and reserves.

FLOAT OR HULL PROPORTIONS
Figure 10 provides proportions of both short- and long-afterbody hulls or floats. The short version, if used for a flying boat, would require an extension to provide an adequate tail-moment arm (TMA) for longitudinal stability. The long version provides such a TMA.
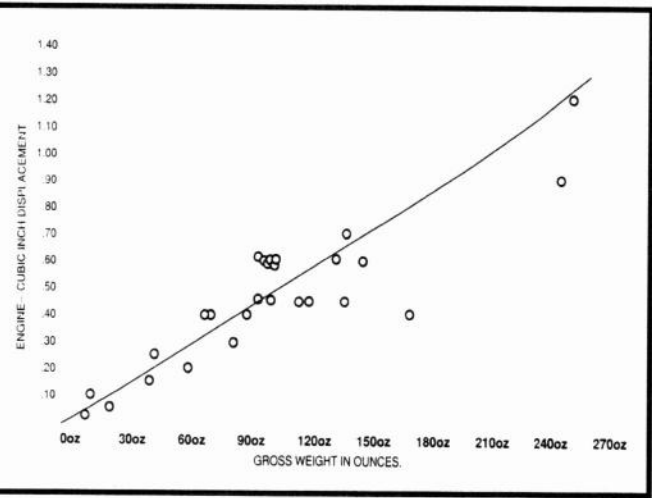

Figure 6.
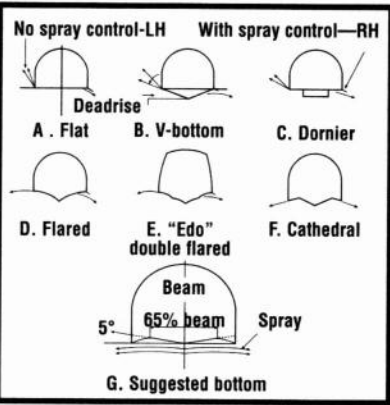*Engine displacement vs. gross weight.*

Figure 8.
Hull and float forebody bottoms and spray control.

Knowing the hull's (or float's) total length and having arrived at the beam, the dimensions of either version are easily calculated. Note that hull or float depths are based on the forebody length, and widths are in percentages of the beam.

For twin-float planes, the calculated beam is divided by 2 to provide each float's beam. Overall float length is 60 to 70 percent of the plane's length. The step depth is based on the total beam and is applied to each float.

WING ANGLE OF INCIDENCE

Chapter 18, "Propeller Selection and Estimating Level Flight Speeds," provides the basis for calculating the angle of incidence necessary to provide adequate lift at the model's estimated level cruise speed. For the Seagull III, this was 0.5 degree.

WING'S STALLING ANGLE AND HUMP TRIM

Chapter 16, "Landing Gear Design," details the calculations necessary to arrive at the wing's stalling angle (at landing-speed Rns, in ground effect and with flaps extended).

The Seagull III's net stalling angle during the takeoff run is 15 degrees. Since the wing is set at 0.5 degree in level flight, the stall would occur 14.5 degrees later.

The Seagull III's hull is the long-afterbody type with a sternpost angle of 10 degrees. Hump trim for this hull is 12 degrees; but because the forebody keel flat is set at *plus* 2 degrees for level flight, this model's *hump* trim angle is reduced to 10
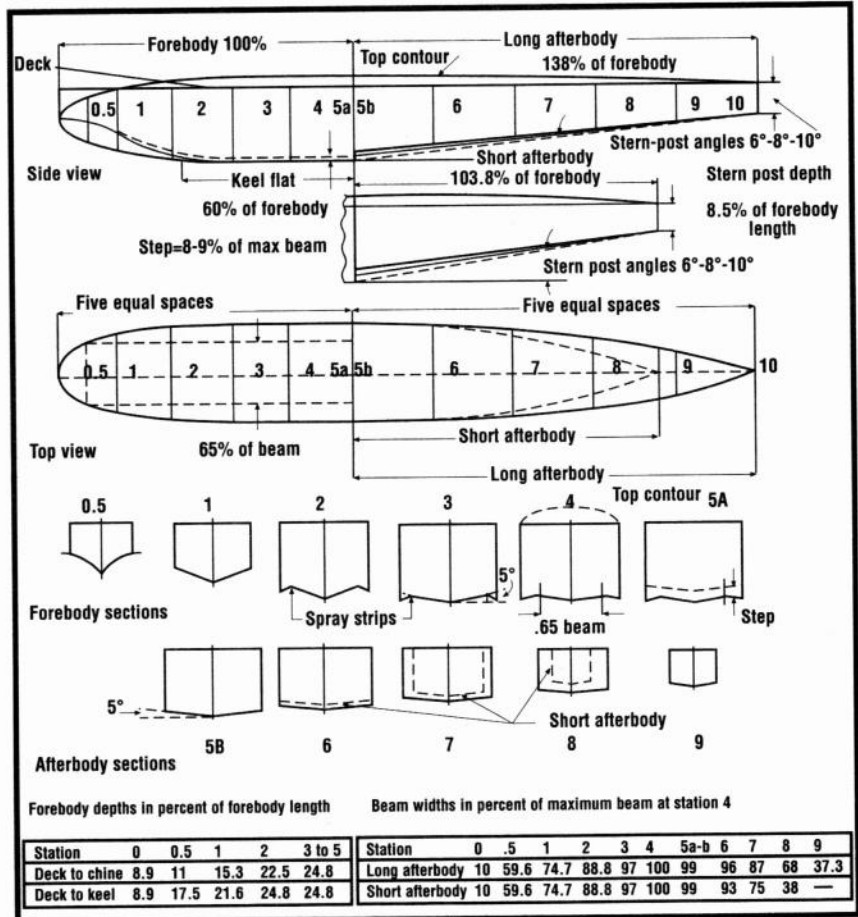

Figure 10.
Hull or float proportions.

degrees. With a wing stall at 14.5 degrees and hump trim of 10 degrees, there is a good safety margin—and wing stall at hump trim is avoided.

Beyond the hump, the elevators take control of the model's trim, and at liftoff speed, moderate up-elevator causes the model to become airborne.

FLYING BOAT LATERAL STABILITY AFLOAT

Flying boats and single-float seaplanes need wing floats to prevent them from tipping over. These must provide sufficient buoyancy to cover a situation in which the model is slowly taxiing crosswind with the hull (or single float) on the crest of a wave and the downwind float in a nearby trough. The upwind wing panel is elevated at a considerable angle to the wind, tending to submerge the down-

wind float or even capsize the model.

These wing floats may be located anywhere from the wing's tip to its root. Mounted close to the root, the floats must be larger to provide the greater buoyancy needed; farther out, they may be smaller and lighter and have less drag.

The planing surfaces of these wing floats must be of adequate area and set at a great enough angle to the hull's keel flat to cause the float to recover quickly while planing when disturbing forces cause the model to heel, lowering one wingtip float to the water surface.

WINGTIP FLOAT DESIGN

Refer to Figure 11. When the model heels to submerge one float, the CG is displaced a distance "X." This distance, in inches, multiplied by the model's weight in ounces, gives the unbalancing moment in inch-ounces. The corrective force is the buoyancy of the submerged float in ounces, multiplied by the distance
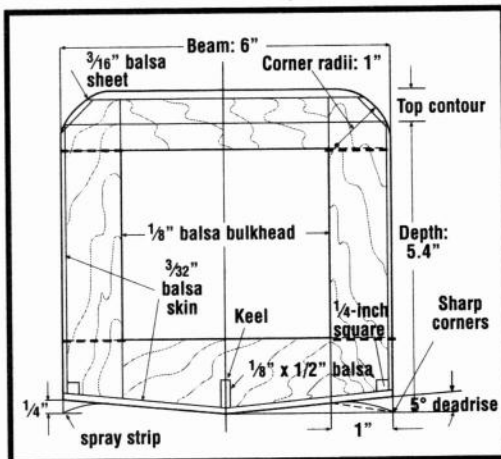

Figure 9.
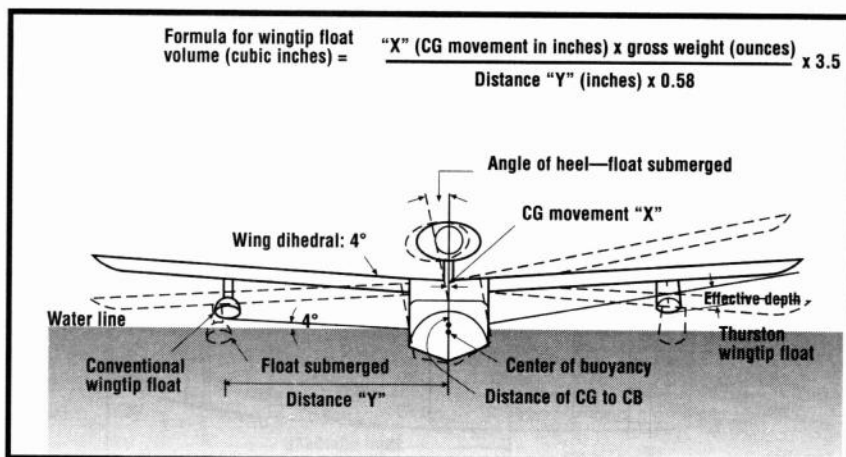*Typical hull or float construction.*

Formula for wingtip float volume (cubic inches) =
$$\frac{\text{"X" (CG movement in inches) x gross weight (ounces)}}{\text{Distance "Y" (inches) x 0.58}} \times 3.5$$

Figure 11.
Wingtip-float-volume calculation.

Seagull III in a flaps-down landing. Note the well-controlled spray from the forebody bottom and the plane's "at the hump" attitude.

3 degrees to the hull's keel flat, as shown. Viewed from the front, the float bottom should parallel the water surface at contact for maximum recovery action when planing.

between the float and hull centerlines. The corrective buoyancy in ounces has to be converted to cubic inches and increased for the reserve buoyancy. The formula in Figure 11 for float volume does all this and includes a 250-percent reserve.

To design a float that has low drag *and* the required volume is not difficult. Lay out a block that will provide the volume in cubic inches that provides the calculated buoyancy (Figure 12). The width is the float beam based on the hull beam² loading; its length will be roughly four times that of the beam. Both depth and beam are calculated using the formulas in Figure 12. Draw the 3-views of your float in and around this block as shown. The float bottoms should be flat with sharp chine corners.

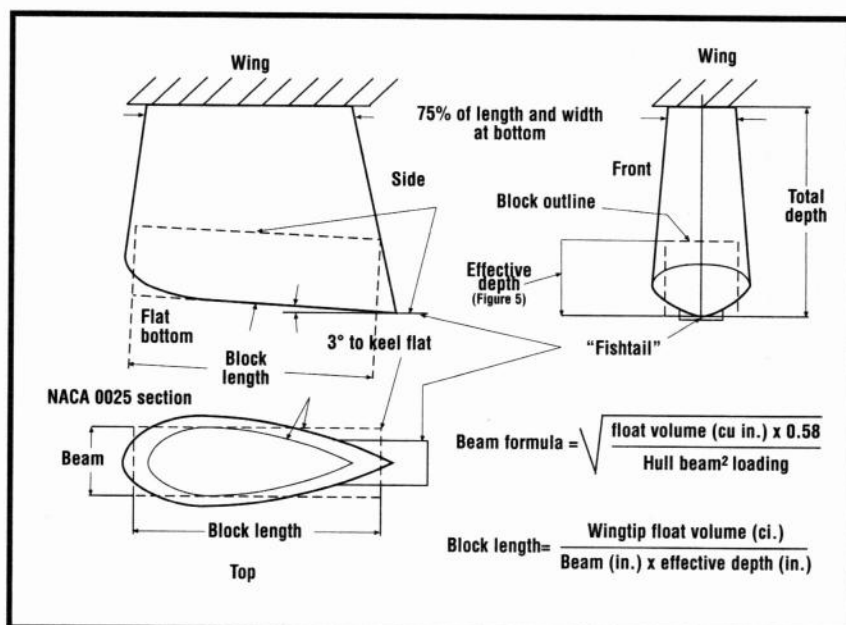The float bottom should be set at

Beam formula = $\sqrt{\dfrac{\text{float volume (cu in.) x 0.58}}{\text{Hull beam}^2 \text{ loading}}}$

Block length = $\dfrac{\text{Wingtip float volume (ci.)}}{\text{Beam (in.) x effective depth (in.)}}$

Figure 13.
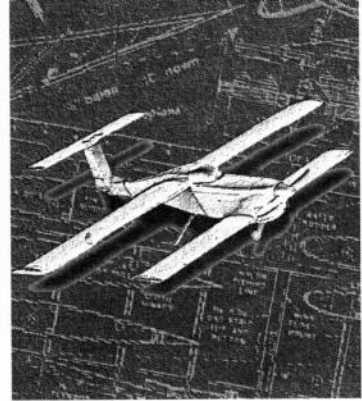**Development of "Thurston" float from basic block.**

THE THURSTON FLOAT
The Seagull III incorporates the Thurston float at its wingtips. These are light and rugged, easily made using sheet balsa and have low drag. Figure 13 provides their design basis.

WATER RUDDERS
Water planes should have water rudders for directional control because the air rudder is ineffective when the plane taxies at low speed. The Seagull III has a water rudder at the base of the air rudder. The Osprey and Seahawk have water rudders operated by separate servos twinned to the receiver's rudder channel. All have good water control. ▲

Beam formula = $\sqrt{\dfrac{\text{float volume (cu.in.) x 0.58}}{\text{Hull beam}^2 \text{ loading}}}$

Float depth = $\dfrac{\text{Float volume (cu.in.)}}{\text{Float beam (in.) x float length (in.)}}$

Figure 12.
Method of developing float lines from basic block of wingtip float volume.

Chapter 25

Basic Proportions for R/C Model Aircraft

Many modelers design their models to reflect their own individuality. For many reasons, they do not choose to follow the detailed and sometimes complex suggestions presented by authors such as me.

The basic proportions presented here are for a range of models to help modelers exercise their urge to originate unique, yet successful, models. They are easy to follow and require a minimum of calculation; and they're divided into six categories represented by:

■ **Figure 1.** Basic proportions for eight models with engine sizes of from .10 to .60.

■ **Figure 2.** Basic twin-float proportions.

■ **Figure 3.** Basic flying boat proportions.

■ **Figure 4.** Basic glider proportions.

■ **Figure 5.** Proportions for aerobatic models powered by .40 to .50 engines.

■ **Figure 6.** Airfoil layout procedure and ordinates for six airfoils. See appendix for performance curves.

Figure 1.
Basic airplane proportions
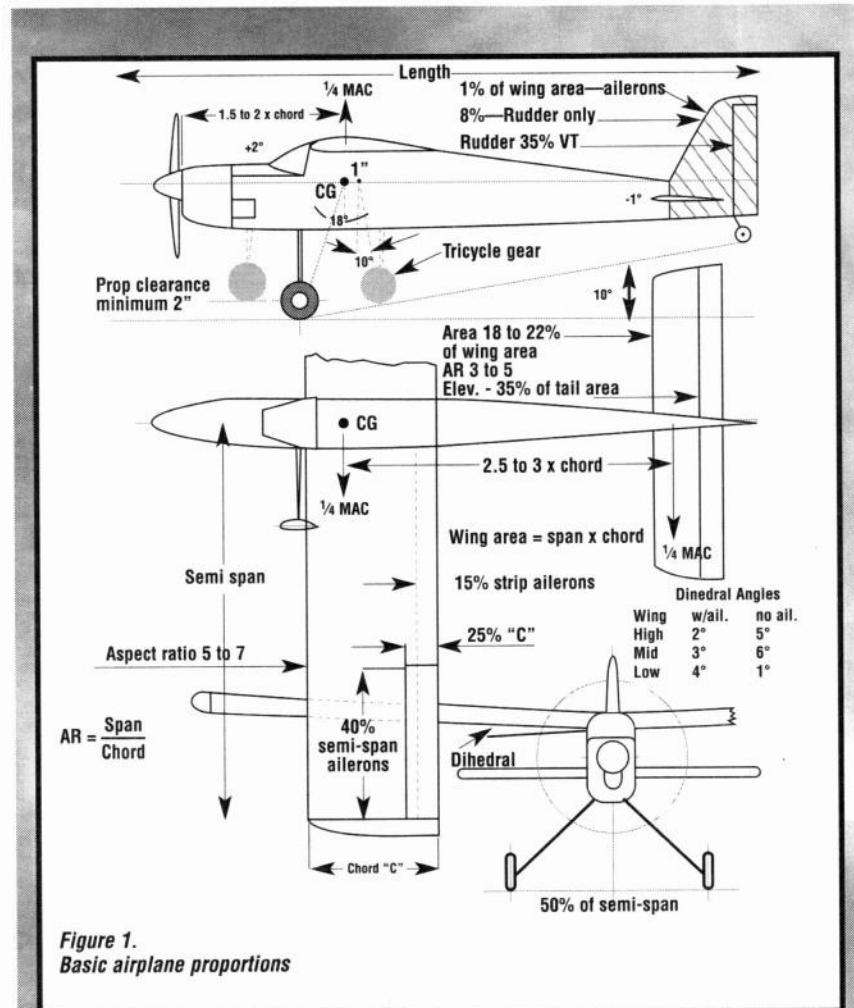
Engine disp. (cid)	Wing area (sq. in.)	Wing loading (oz./sq. ft.)	Estimated gross wt. (oz.)	Power loading (oz./cid)	Prop (d x p) (in.)	Wheel diameter (in.)	Speed at C_L 2.0 (mph)
0.10	300	14	29	290	7x4	1.75	42
0.15	325	15	34	226	8x4	1.75	44
0.25	450	17	53	212	9x4	2	46
0.35	550	19	73	208	9x6	2	48
0.40	600	19	79	198	10x6	2.25	48
0.45-6	700	20	97	215	11x6	2.5	49
0.50	750	20	104	208	11x6	2.5	49
0.60-1	800	20	111	185	12x6	3.0	49

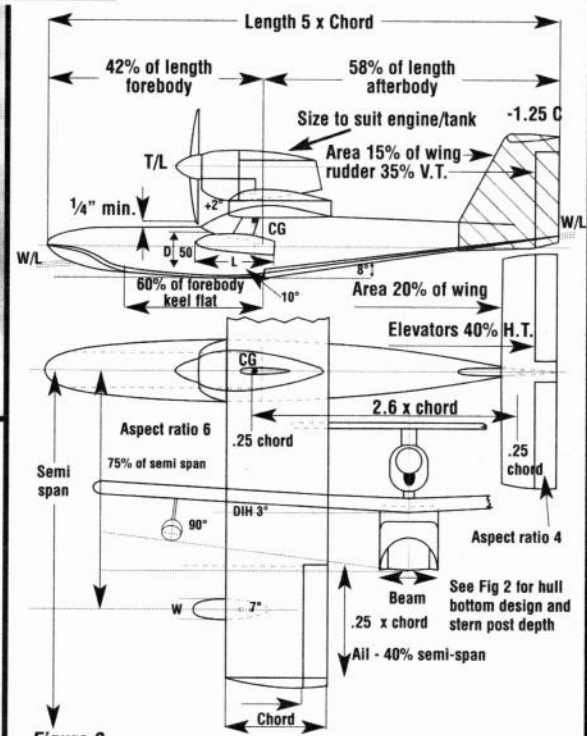| Eng. disp. (cid)	Max. hull beam (in.)	Step depth (in.)	Wing float dimensions (in.)		
			Depth	Length	Width
0.10	4.75	7/16	1.125	5.0	1.50
0.15	5.00	15/32	1.125	6.0	1.75
0.25	5.00	15/32	1.25	7.0	2.00
0.35	5.75	1/2	1.5	7.5	2.25
0.40	6.00	9/16	1.5	8.0	2.50
0.45-6	6.5	19/32	1.75	8.5	2.50
0.50	6.75	5/8	2	9.0	2.75
0.60-1	7.00	11/16	2	9.0	3.00

Figure 3.
Basic flying boat proportions.
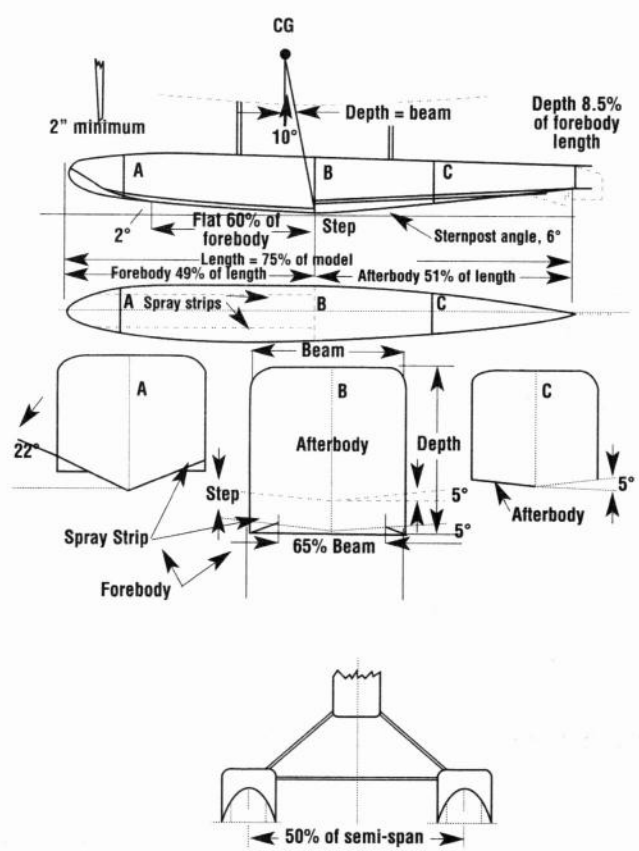
Eng. disp. (cid)	Max float beam (in.)	Step depth (in.)
0.10	2.375	7/16
0.15	2.5	15/32
0.25	2.5	15/32
0.35	2.825	1/2
0.40	3.00	9/16
0.45-6	3.25	19/32
0.50	3.375	5/8
0.60-1	3.5	11/16

Figure 2.
Basic twin float proportions.

Figure 4B.
Basic glider proportions.
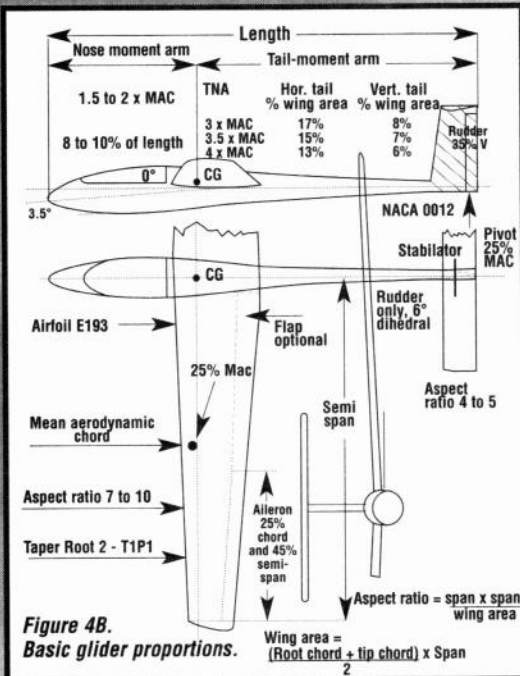
Free from engine-displacement restrictions, glider dimensions and weight vary widely.

Wing area	500 to 1,000 sq. in.
Span	60 to 100 in.
Aspect ratio	7 to 15
Wing loadings	6.5 to 12 oz. per sq. ft.
Weight	25 to 75 oz.
Controls	Rudder and elevator only to aileron, rudder, elevator, flaps (or spoilers)
Wing airfoils	Clark Y, E193, E197—your choice
Tail airfoils	NACA 0012, E168
Control weights	Rudder and elevator only—6.25 oz. (receiver, 2 small servos, 250mAh battery)
	Aileron, rudder, elevator, flaps (spoilers)—12 oz. (4 standard servos, 500mAh battery)

Figure 5.
Basic aerobatic airplane proportions.
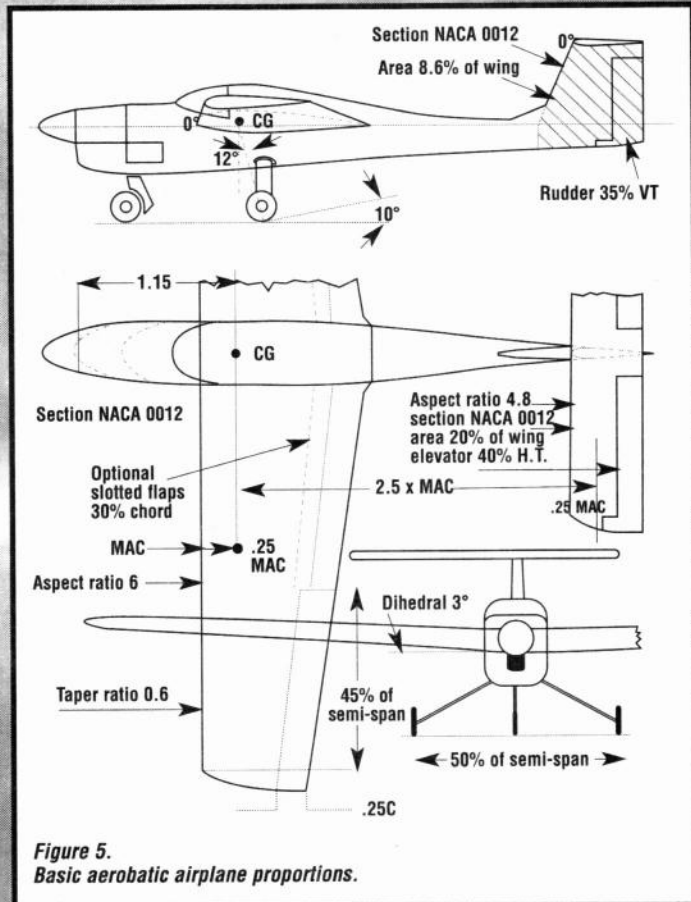
All five models are powered by .46 engines and have APC 10x9 props

Wing area	Wing chords (in.)		Wingspan	Weight	Wing loading
(sq. in.)	Root	Tip	(in.)	(oz.)	(oz./sq. ft.)
400	10.2	6.12	49	82	29.5
500	11.4	6.85	54.75	87	25
600	12.5	7.5	60	92	22
700	13.5	8.1	64.80	97	20
800	14.4	8.7	69.25	102	18.4

AIRFOIL LAYOUT PROCEDURE

Every serious modeler should know how to develop an airfoil from its published ordinates.

These describe each airfoil by three measurements:

■ Chord length and stations along the chord.

■ Depth (ordinates) above and below the chord line at each station.

■ Leading-edge radius and location of its center.

All measurements are *percentage of the chord length*. An exception is the Clark Y, whose depth is measured from its flat bottom, *not* its chord line. With the bottom level, the Clark Y is at an angle of attack of 2 degrees, measured on its chord line.

This author measures the stations in $1/10$-inch intervals, along

the chord line, from the leading edge. Some interpolation is necessary.

Depths above and below the chord line are measured in $1/50$-inch intervals; some interpolation is needed. The necessary calculations are simple.

Stations

Chord length x station percentage. Example: chord 7 in. x station 50 is 3.5 inches from the leading edge.

Ordinates (depths)

Chord length (in.) x percent depth
2

Example: a 7-inch chord with 7.88% depth at station 50 is 7 ÷ 2 x 7.88 = 27.58 fiftieths above the chord line at station 50.

Most calculators have a "Constant" feature. Using it, the chord length is entered once; the station or ordinate percentages only are needed to complete the calculation.

Note that ordinates below the chord line are negative, e.g., -2.5.

Nose radius

Quoted as a percentage of the chord's length, NACA airfoils, such as NACA 2412, locate the *center* of the nose radius by "slope of radius through the end of chord $2/20$." Simply measure 2 inches from the chord leading edge; erect a vertical line 0.2 inch high, above the chord line. The diagonal, from the chord line to the top of the vertical line, locates the center of the nose radius. On a 10-inch wing chord, this radius would be 0.158 inch. Laying out one airfoil section takes 15 to 20 minutes. For an untapered wing, this is no problem. However, for a high-aspect-ratio tapered wing with many different ribs, this procedure is both long and tedious.

Given chord lengths, airfoil setion designations, skin thickness/spar location and sizes various companies can provide very accurate computer-generated airfoil sections at a reasonable cost.

Figure 6A illustrates a layout of a 7-inch chord E193 section with vertical line at each chord station. In Figure 6B, the ordinate lengths, above and below the chord line have been measured. Using French curves, the points are joined smoothly to outline the airfoil. ▲
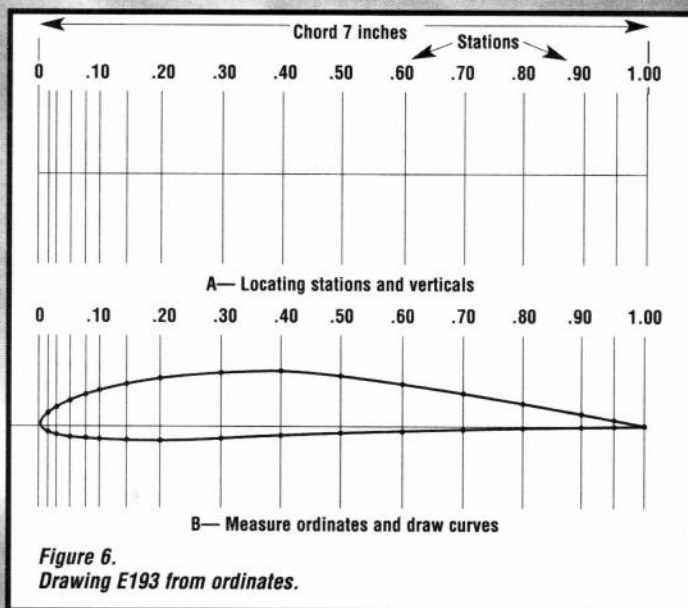

Figure 6.
Drawing E193 from ordinates.

| STATION % OF CH	FLAT BOTTOM				SEMISYMMETRICAL				SYMMETRICAL			
	CLARK Y		E193		NACA 2412		E197		NACA 0012		E168	
	U	L	U	L	U	L	U	L	U	L	U	L
0	3.50	3.50	0	0	0	0	0	0	0	0	0	0
1.25	5.45	1.93	1.78	-1.14	2.15	-1.65	2.00	-1.46	1.894	-1.894	1.95	-1.95
2.50	6.50	1.47	2.44	-1.30	2.99	-2.27	2.64	-1.82	2.615	-2.615	2.60	-2.60
5.0	7.90	0.93	3.76	-1.78	4.13	-3.01	4.12	-2.60	3.555	-3.555	3.68	-3.68
7.5	8.85	0.63	4.74	-2.00	4.96	-3.46	5.16	-3.14	4.2	-4.200	4.34	-4.34
10	9.60	0.42	5.52	-2.16	5.63	-3.75	6.08	-3.46	4.683	-4.680	4.84	-4.84
15	10.68	0.15	6.68	-2.24	6.61	-4.10	7.36	-3.96	5.345	-5.340	5.60	-5.60
20	11.36	0.03	7.54	-2.40	7.26	-4.23	8.24	-4.26	5.738	-5.738	6.06	-6.06
25	—	—	—	—	7.67	-4.22	—	—	5.941	-5.941	—	—
30	11.70	0	8.5	-1.78	7.88	-4.12	9.340	-4.20	6.002	-6.002	6.18	-6.18
40	11.40	0	8.48	-1.40	7.80	-3.80	9.38	-3.88	5.803	-5.803	5.80	-5.80
50	10.52	0	7.76	-1.04	7.24	-3.34	8.76	-3.00	5.294	-5.294	4.88	-4.88
60	9.15	0	6.66	-0.60	6.36	-2.76	7.40	-2.38	4.563	-4.563	3.76	-3.76
70	7.35	0	5.2	-0.36	5.18	-2.14	5.48	-1.64	3.664	-3.664	2.86	-2.86
80	5.22	0	3.58	-0.08	3.75	-1.50	3.70	-0.96	2.623	-2.623	1.80	-1.80
90	2.80	0	2.0	-0.01	2.08	-.82	2.16	-0.38	1.448	-1.448	0.84	-0.84
95	1.49	0	0.84	-0.00	1.14	-.48	1.00	-0.20	0.807	-.8070	0.40	-0.40
100	0.12	0	0	-0.00	0.13	-0.13	0	0	0.126	-0.126	0	0
LE radius	1.50		0.67		1.58 Slope 2/20		0.84	0	1.58		1.24	

Key: CH = chord; U = upper; L = lower.

Chapter 26
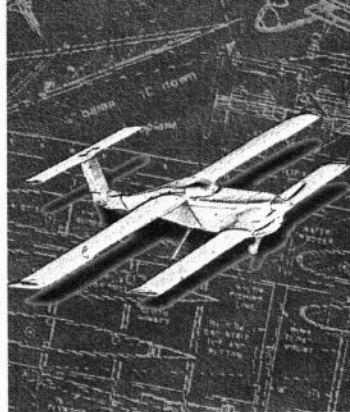
Construction Designs

H ere are a few of the innov-
ative R/C airplane models
that the author has
designed. The various sport
planes, canards, three-surface and
amphibious designs and gliders
included illustrate a variety of the
design elements and approaches
described in this book.
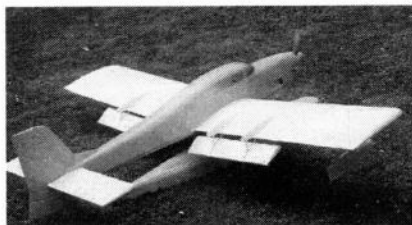
SEAHAWK

Type	amphibious sport
Gross weight	110 oz. (land);
	121 oz. (water)
Wing area	655 sq. in.
Wing loading	24.3 oz./sq. ft.
	(land); 26.6 oz./sq. ft. (water)
Beam^2 loading	3.33 oz.
Engine	.46
Prop	11x8
Power loading	239.9 oz./cid(land);
	263 oz./cid (water)

(Model Airplane News, Oct. '92)
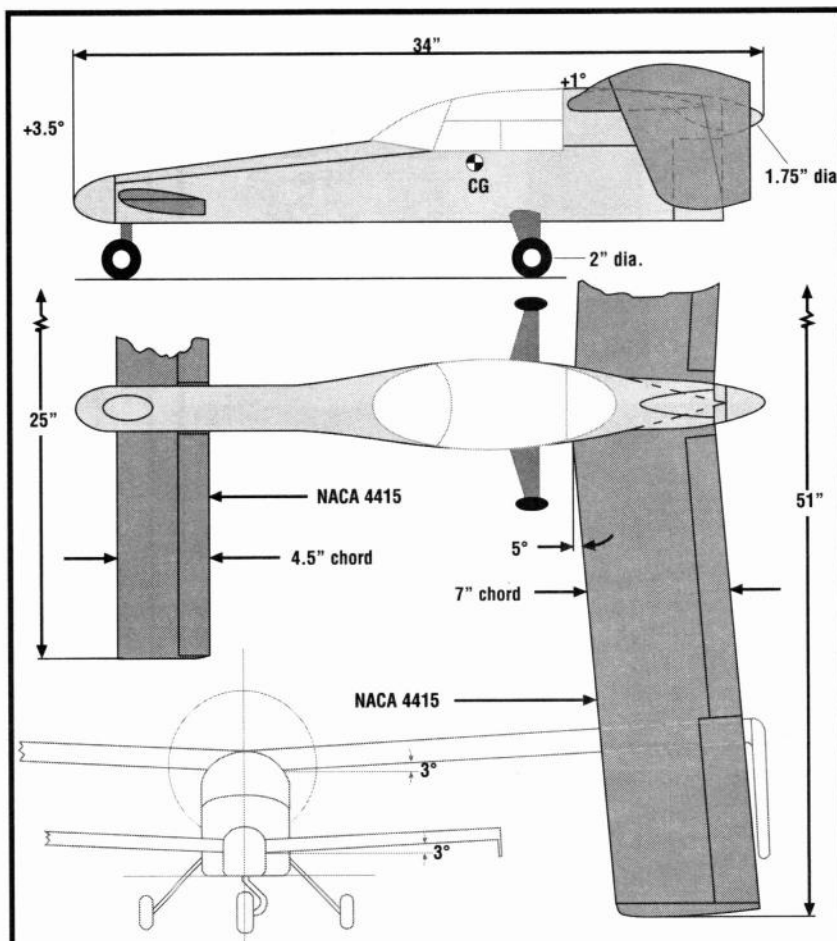
CANADA GOOSE

Type	canard
Gross weight	75 oz.
Wing area	444 sq. in.
Wing loading	24.3 oz. sq. ft.
Engine	.30 to .35
Prop	10x5 or 10x6 pusher
Power loading	215 oz./cid

(Model Airplane News, Jan. '81)
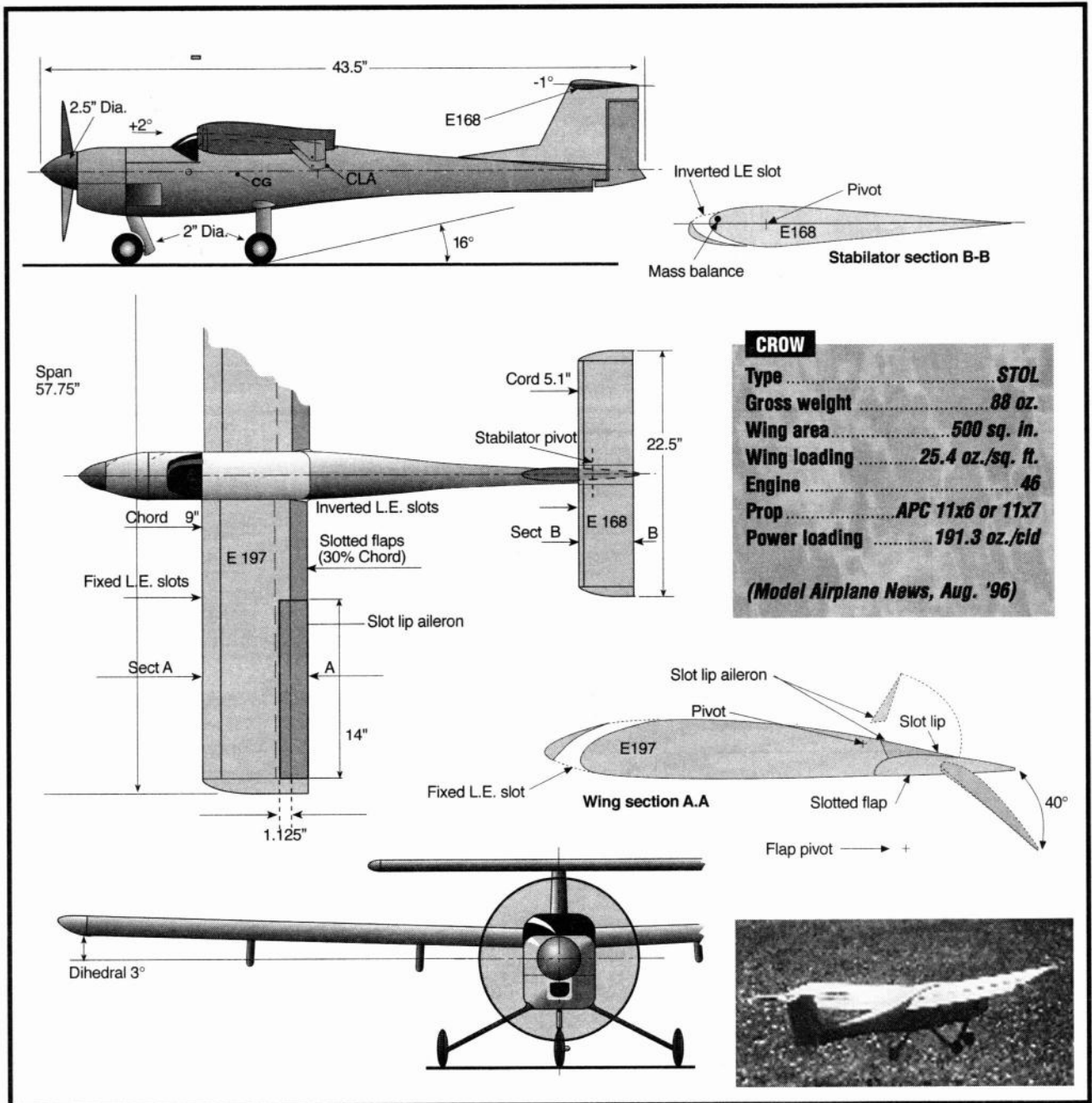
-1°

0° CG CLA

2.5" dia.

2" dia.

10°

Wingspan—61.5"

24.625"

E168—5.1" chord

E168—5.1" chord
Slotted flap
30% chord

Dihedral—3°

E197M—
10.1" chord

15°

15"

SWIFT

Type	*sport*
Gross weight	*92 oz.*
Wing area	*600 sq. in.*
Wing loading	*22 oz./sq. ft.*
Engine	*.46 cid*
Prop	*APC 10x9*
Power loading	*200 oz./cid*

(Model Airplane News, Sept. '93)
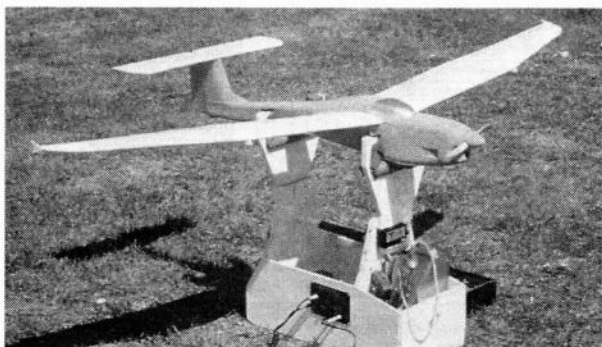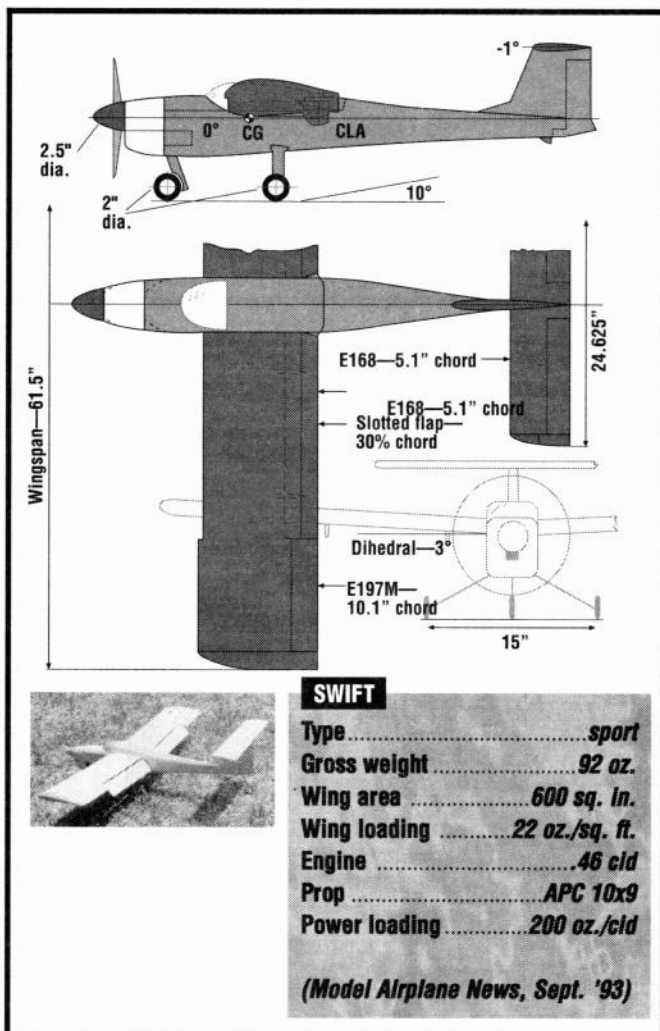
DOVE

Type	*powered glider*
Gross weight	*55.375*
Wing area	*602 sq. in.*
Wing loading	*13.16 oz./sq. ft.*
Engine	*.15*
Prop	*APC 8x4*
Power loading	*367 oz./cid*

(Model Airplane News, Nov. 1994)

43.75"

+1.6° +0.75"

CG NP CLA

0° 15°

Slotted flaps

39.75"

56.6875"

E214

E197

E168

22"

8"

5"

E197M

5.7"

8.25"

WILD GOOSE

Type	*three-surface design*
Gross weight	*97 oz.*
Wing area	*225 sq. in. (foreplane); 450 sq. in. (aft plane); 112 sq. in. (horizontal tail)*
Wing loading	*20.7 oz./cid*
Engine	*46 SF*
Prop	*APC 11x6*
Power loading	*210.8 oz./cid*

(Model Airplane News, Jan. '96)

43.5"

2.5" Dia.
+2°
-1°
E168
CG
CLA
2" Dia.
16°

Inverted LE slot
Pivot
E168
Mass balance
Stabilator section B-B

Span
57.75"

Cord 5.1"
Stabilator pivot
22.5"
E 168
Sect B
B

Chord 9"
Inverted L.E. slots
E 197
Slotted flaps
(30% Chord)
Fixed L.E. slots
Slot lip aileron
Sect A
A
14"
1.125"
Dihedral 3°

CROW	
Type	STOL
Gross weight	88 oz.
Wing area	500 sq. in.
Wing loading	25.4 oz./sq. ft.
Engine	46
Prop	APC 11x6 or 11x7
Power loading	191.3 oz./cid

(Model Airplane News, Aug. '96)

Slot lip aileron
Pivot
E197
Slot lip
Fixed L.E. slot
Wing section A.A
Slotted flap
40°
Flap pivot → +

OSPREY	
Type	sport/float plane
Gross weight	113 oz.; 143 oz. (w/floats)
Wing area	768 sq. in.
Wing loading	20.92 oz./sq. ft.; 26.5 oz. (w/floats)
Engine	45
Prop	APC 12x6
Power loading	251 oz./cid; 317 oz./cid (w/floats)

(Model Builder, June '91)

E214 @ +3.5° E197 @ +1.25°

78.4"

15.8"

2.5"

76.5 sq. in.

117 sq. in.

21.6"

Outer panel AC

CG   SM

Inner panel AC

NP

90°

3.6" chord

5.6" chord

25°

6.46" average chord

Root chord— 10.8"

Rib "A"

Aileron— 0.25% chord

Spoil-flap— 0.15% chord

Dihedral—5°

25.625"

CG
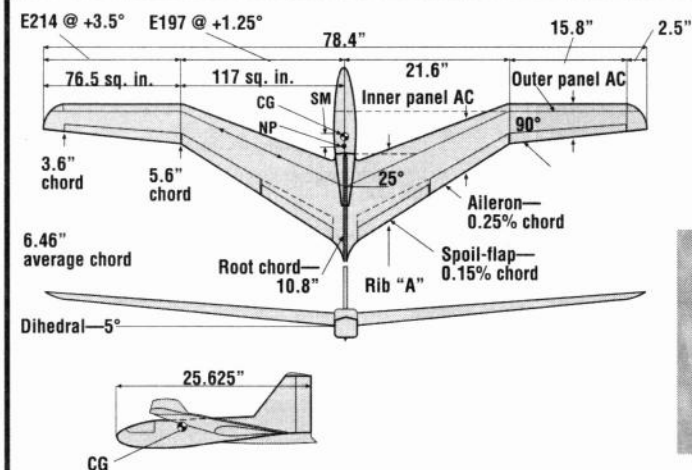
PLOVER

Type	glider
Gross weight	32 oz.
Wing area	507 sq. in.; AR—12
Wing loading	9.09 oz./sq. ft.
Controls	elevator, aileron, rudder, spoil-flaps
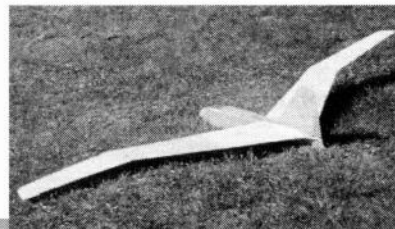
WASP

Type	tandem-wing biplane
Gross weight	36.25 oz.
Wing area	300 sq. in.
Wing loading	17.42 oz./sq. ft.
Engine	15 cid
Prop	7x4
Power loading	241 oz/cid

(RC Models and Electronics, Feb. '88)

26.3"

NACA scoop

10°

Clark-Y

3°   1.75°

Aileron

Elevators

30"

CG

5"

4°

4°

1.75" dia.
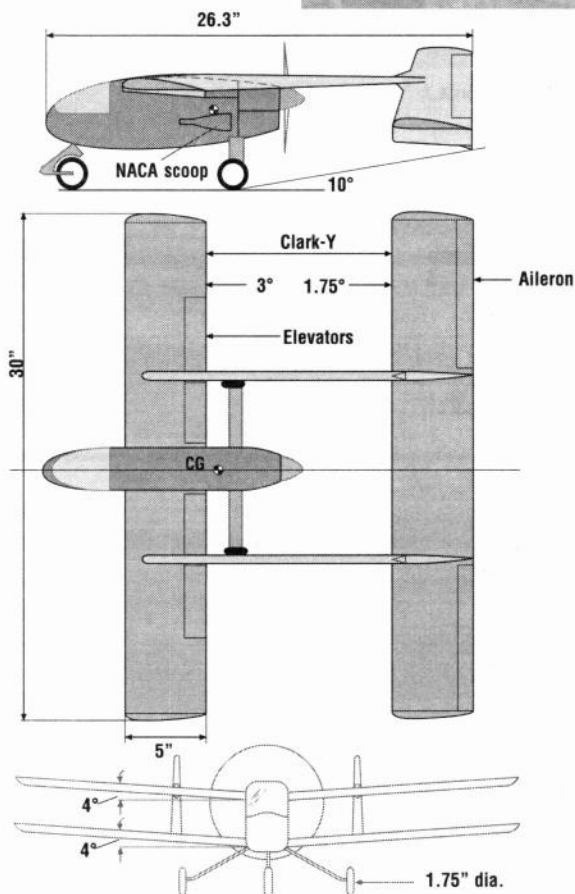
SWAN

Type	canard
Gross weight	115 oz.
Wing area	669 sq. in.
Wing loading	24.75 oz./sq. in.
Engine	45 cid
Prop	10x6 pusher
Power loading	211 oz./cid

(Model Builder, Oct. '89)
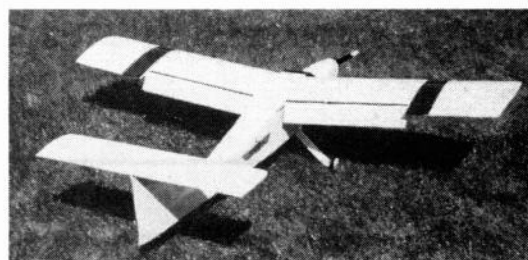
SNOWY OWL

Type	sport
Gross weight	98 oz.
Wing area	643 sq. in.
Wing loading	22 oz./sq. ft.
Engine	40
Prop	11x6
Power loading	245 oz./cid

(RC Modeler, Jan. '89)
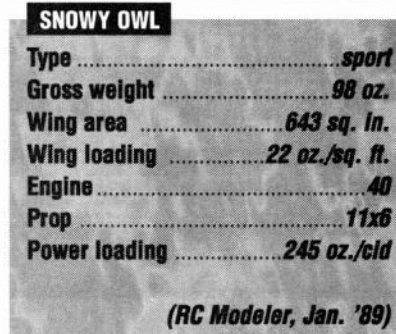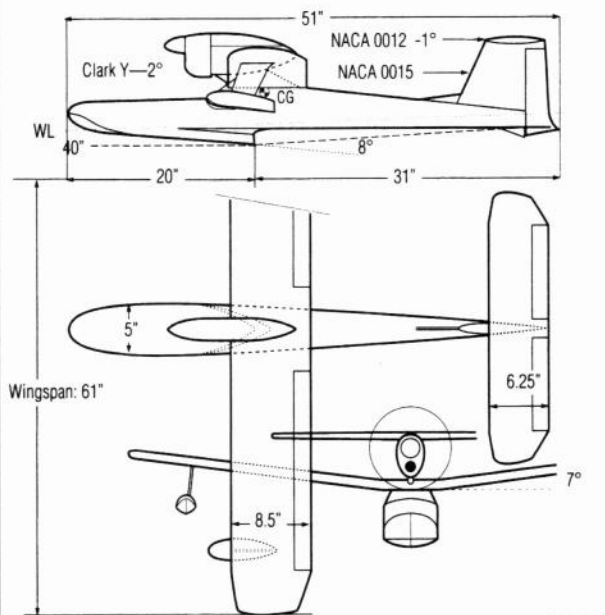
FLAMINGO

Type	*flying boat*
Gross weight	*74 oz.*
Wing area	*500 sq. in.*
Wing loading	*21.3 oz./sq. ft.*
Engine	*35cid*
Prop	*9x6*
Power loading	*211 oz./cid*

(Model Airplane News, Oct. '57)

SEA LOON

Type	*amphibious flying boat*
Gross weight	*40 oz.*
Wing area	*250 sq. in.*
Wing loading	*.23 oz./sq. ft.*
Beam² loading	*3.26 oz./sq. in.*
Engine	*15*
Prop	*7x4 pusher*
Power loading	*266.6 oz./cid*

(Model Aviation, Oct '87)

SPARROWHAWK

Type	*sport*
Gross weight	*38 oz.*
Wing area	*250 sq. in.*
Wing loading	*22 oz./sq. ft.*
Engine	*15cid*
Prop	*7x6*
Power loading	*253.3 oz./cid*

(Model Aviation, Jan. '87)
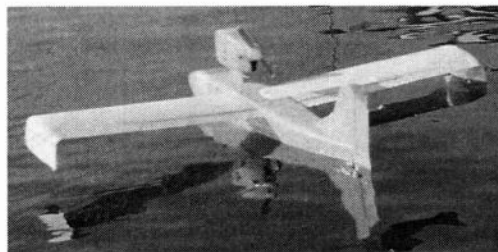
SEAGULL III

|	
Type	*flying boat*
Gross weight	*112 oz.*
Wing area	*694 sq. in.*
Wing loading	*23.3 oz./sq. ft.*
Beam² loading	*3.11 oz./sq. in.*
Engine	*46 cid*
Prop	*11x8 pusher*
Power loading	*243 oz./cid*

(RC Modeler, Oct. '92)

Appendix

●●●●●●●●●●●●●●●●●●●●●●●●●●

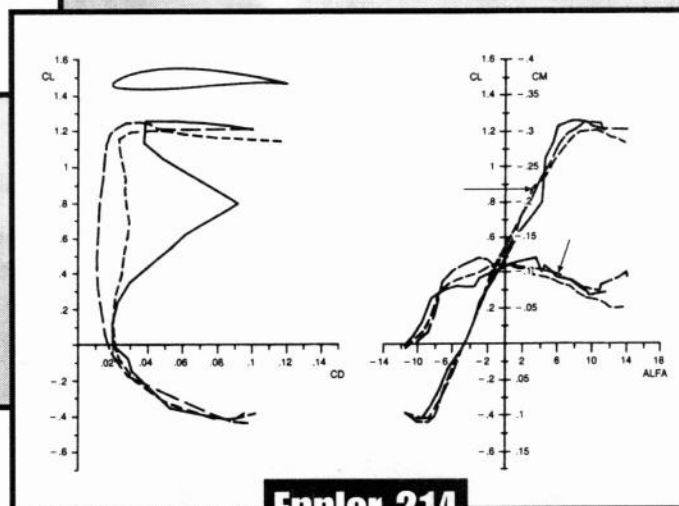▶ Eppler 197 is a moderately cambered airfoil with a soft, gentle stall. It has very low drag.
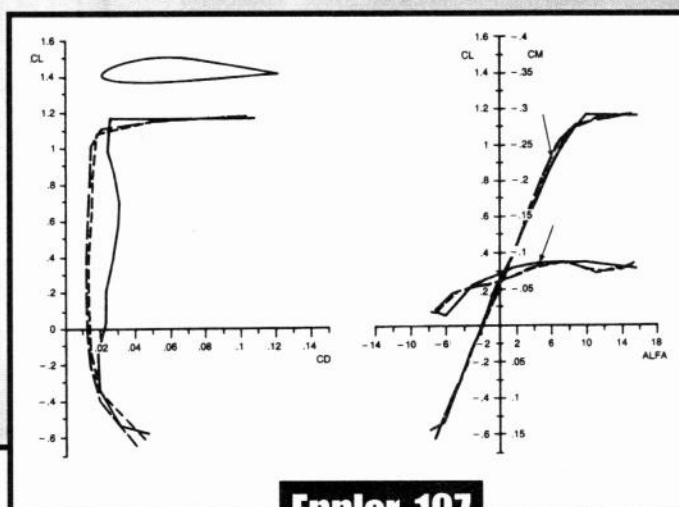
Eppler 197

◀ Eppler airfoil 168 is symmetrical with no pitching moment, except at the stall, during which the airfoil becomes nose-down and is stabilizing.
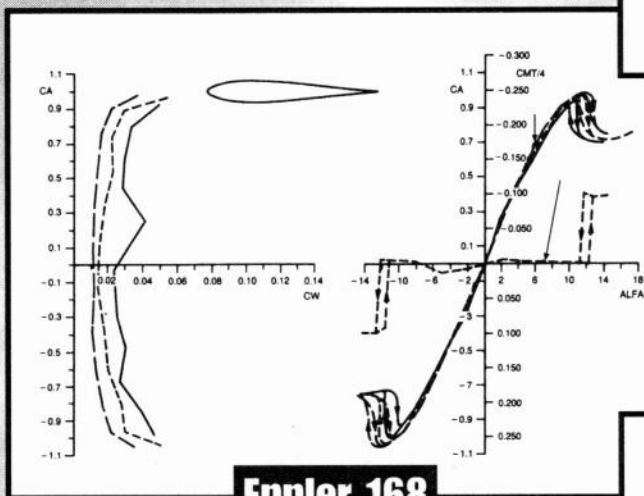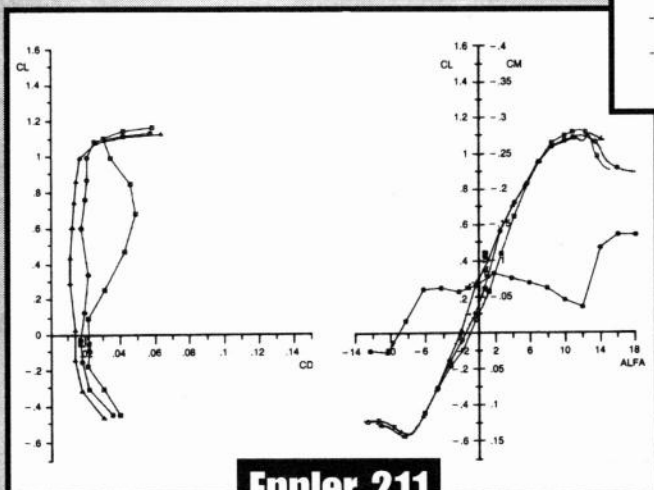

Eppler 168

▶ Eppler 214 is an aft-loaded airfoil that has good lift. It starts to lift at a negative angle of attack and has camber near the trailing edge.
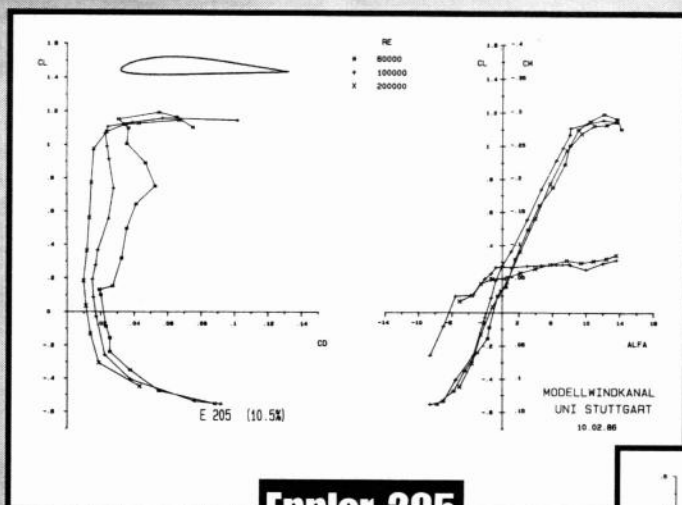

Eppler 214

Eppler 211

◀ Eppler 211 is a foreplane airfoil with a sharp stall at low Rn. Note the reduction in angle of attack of zero lift as Rn is reduced.
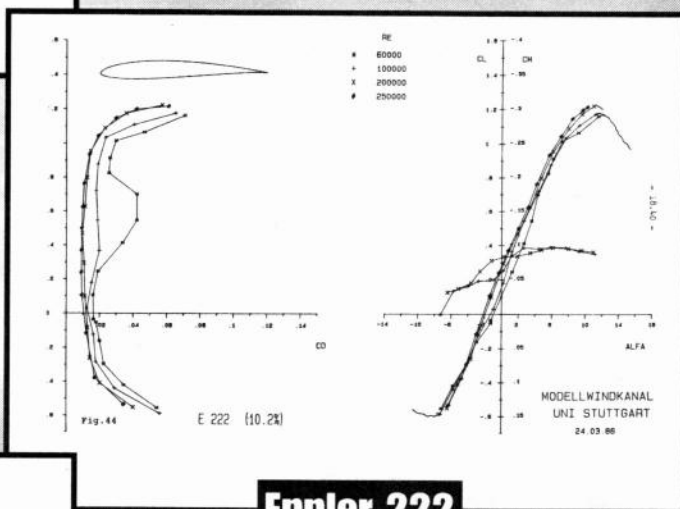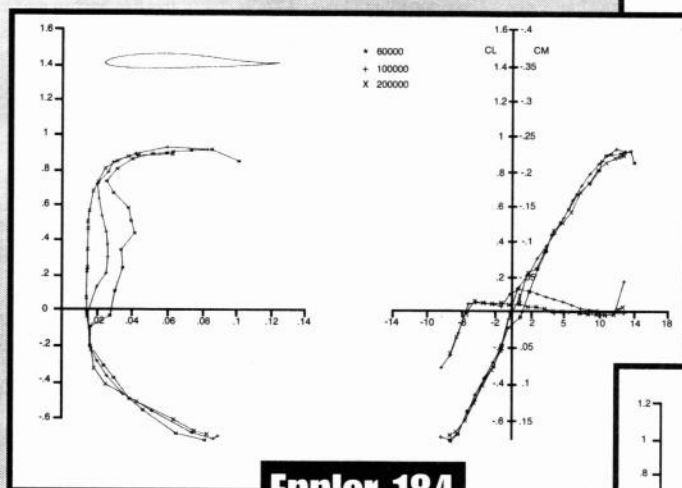
Eppler 205 is moderately cambered. It has good lift and low drag at low Rn and is thinner then Eppler 197.

Eppler 205

Eppler 222 is also moderately cambered. It has good lift and low drag at low Rn and is thinner than Eppler 197.
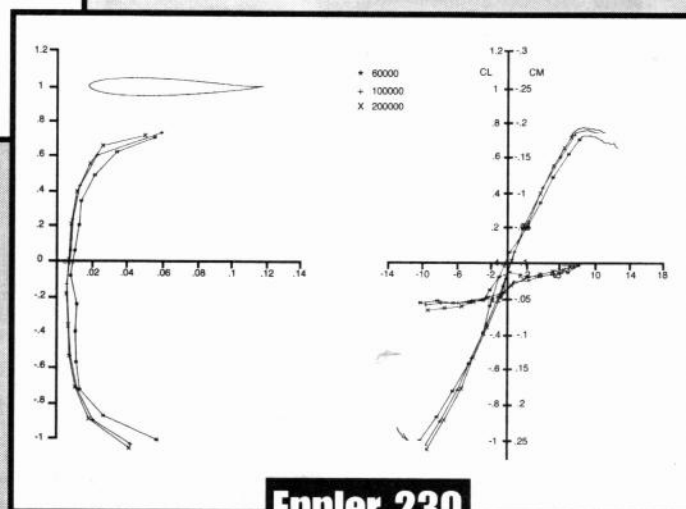
Eppler 222

Eppler 184 is a reflexed airfoil with a low, nose-down pitching moment.

Eppler 184

Eppler 230 has a reflexed trailing edge and has a nose-up pitching moment.

Eppler 230

A comprehensive guide to designing radio control model airplanes

BASICS OF
R/C MODEL
AIRCRAFT DESIGN

PRACTICAL TECHNIQUES FOR BUILDING BETTER MODELS

- **CHOOSING AIRFOILS**
- **WING LOADING**
- **CG LOCATION**
- **BASIC PROPORTIONS**
- **AEROBATIC DESIGN**

Have you considered customizing one of your models to enhance its performance? or designing your own R/C model airplane? If you have, this book contains a gold mine of practical guidance, hints and tips that will guarantee your scratch-building and model-customizing success. From aerodynamics to structures and control surfaces, Andy Lennon offers practical solutions and an understanding of why they work.

Which type of airfoil should be used? How should the weight and balance be calculated? How can a plane be designed so it will be stable and have very little drag? Should flaps be incorporated, and are they beneficial in reducing landing speeds? With several decades of designing and flying successful model aircraft, Andy answers these questions and many more in a practical, concise way that will help you with nearly any project currently on your workbench.

Andy's book presents a thorough and comprehensive introduction to the intriguing world of model aerodynamics. It's jam-packed with graphs and charts that are easy to understand and extremely helpful to the new or seasoned designer. Airfoil selection, the all-important wing-loading calculation and finding the proper CG location are just some of the topics to be found in the opening chapters.

Learn how to design efficient horizontal and vertical tails, determine horizontal tail incidence and estimate the downwash that affects that incidence. Andy explains why these estimates are necessary and tells how to do it. Reducing drag is a constant battle for the model designer; Andy shows how to do it by properly shaping fuselages, streamlining landing-gear wires, and correctly mounting the wing on the fuselage. If you're seeking improved aerobatic performance or a design that will perform well in a high-G turn, Andy again spells out the answers.

Interested in building unconventional models that utilize canards or three lifting surfaces? Andy clearly sets out the design principles. Secrets for successful seaplanes and floatplanes are also covered. Andy tops off his book with a look at a few of his published designs, all of which incorporate the design principles presented in this unique volume.

Whatever your modeling background, this book will be a valuable reference source in your R/C library, and it will never be outdated. Filled with timeless insights that range from the findings of early NACA reports to approaches adapted in modern aircraft, this work will serve you well time and time again.
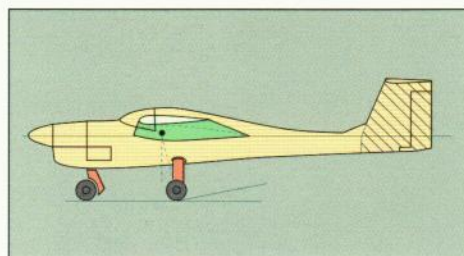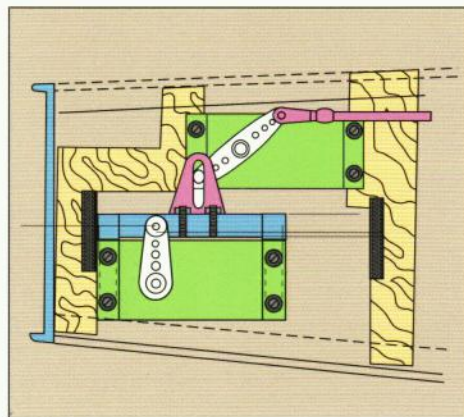
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